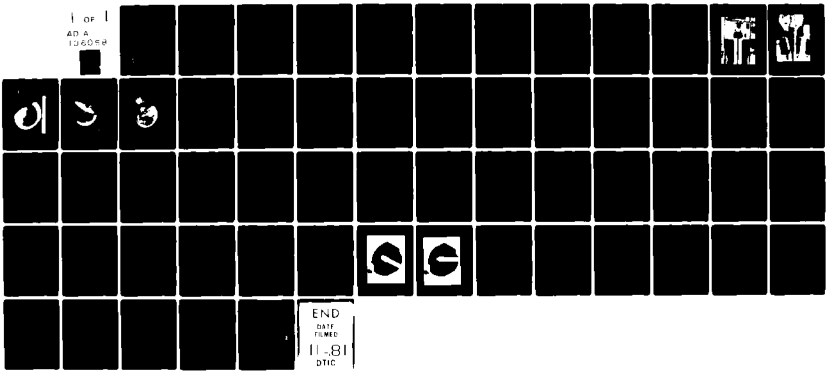
AD-A106 058 NAVAL SURFACE WEAPONS CENTER SILVER SPRING MD F/G 20/13
HEAT-TRANSFER AND PRESSURE TESTS ON AN OBLATE ELLIPTIC NOSETIP --ETC(U)
JUN 81 M D JOBE
UNCLASSIFIED NSWC/MP-81-259 NL

1 OF 1
AD A
106058



NSWC MP-81-259

WIND TUNNEL DATA REPORT

HEAT-TRANSFER AND PRESSURE TESTS ON AN OBLATE ELLIPTIC NOSETIP IN THE NSWC/WO HYPERSONIC TUNNEL AT MACH NUMBER 5 (WTR-1346)

BY

M. D. JOBE

STRATEGIC SYSTEMS DEPARTMENT

JUN[redacted]81

Approved for public release; distribution unlimited.

NAVAL SURFACE WEAPONS CENTER

Dahlgren, Virginia 22448 • Silver Spring, Maryland 20910

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
NSWC MP 81-259

2. GOVT ACCESSION NO.
AD-A106 058

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
HEAT-TRANSFER AND PRESSURE TESTS ON AN OBLATE ELLIPTIC NOSETIP IN THE NSWC/WO HYPERSONIC TUNNEL AT MACH NUMBER 5 (WTR 1346)

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
M. D. JOBE

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
NAVAL SURFACE WEAPONS CENTER (K24)
WHITE OAK
SILVER SPRING, MARYLAND 20910

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
FY7653-8100301

11. CONTROLLING OFFICE NAME AND ADDRESS

12. REPORT DATE
JUNE 1981

13. NUMBER OF PAGES
59

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
BMO/MNRTE
NORTON AFB
LOS ANGELES, CALIFORNIA

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Elliptic nosetip	Surface roughness	Enthalpy ratio
Heat transfer	Augmented heating	Hypersonic
Pressure distribution	Transition	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An extensive data base on a 2:1 elliptical nosetip shape to be utilized for verification of the AVCO MTSCT three-dimensional transition code was generated in the NSWC Hypersonic Tunnel at Mach Number 5. Four nosetip models in which the surface roughness was varied from a smooth wall to a roughness value of 10 mils were tested. The first three nosetips were instrumented with 112 backfaced chromel-alumel thermocouples. The fourth model (i.e., 10-mil roughness) instrumentation consisted of 67 thermocouples and 31 Statham pressure

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

transducers. The test matrix consisted of sixty runs where the variables included angle-of-attack, tunnel Reynolds number, and wall enthalpy ratio.

FOREWORD

An extensive data base on a 2:1 elliptical nosetip shape to be utilized for verification of the AVCO MTSCT three-dimensional transition code was generated in the NSWC/WO Hypersonic Tunnel at Mach Number 5. The tests were conducted during the period 7-17 April 1981. Four nosetip models with surface roughness values based on a 30% probability of exceedence (K_{30}) of 0, 1.29, 3.26, and 10 mils were tested. The first three nosetip models were instrumented with 112 back-faced chromel-alumel thermocouples. The fourth model (i.e., 10-mil roughness) instrumentation consisted of 67 thermocouples and 31 Statham pressure transducers. The test matrix consisted of 60 runs where the variables included angle of attack, tunnel Reynolds number, and wall enthalpy ratio.

This work was performed at the request of the Ballistic Missile Office in support of the Maneuvering Thermodynamics and Shape Change Technology (MTSCT) Program. These tests were directed by Mr. A. Todisco, AVCO Systems Division, Wilmington, Massachusetts. This report describes the test procedures and the data reduction and transmittal methods.

C. A. Fisher

C. A. FISHER
By direction

CONTENTS

	Page
INTRODUCTION	5
MODELS AND INSTRUMENTATION	5
TEST CONDITIONS	14
DATA ACQUISITION AND REDUCTION	21
SURFACE ROUGHNESS CHARACTERIZATION	24
DATA FORMAT	26
BIBLIOGRAPHY	47
NOMENCLATURE	49
APPENDIX A Surface Roughness Characterization	A-1

ILLUSTRATIONS

Figure		Page
1	Model Drawing	6
2	Pressure Port Connection	7
3	Illustration of Thermocouple and Pressure Tap Locations	8
4	Model G-3 Retracted Into Cooling Box--Top View	9
5	Model G-1 Injected Into Test Cell--Side View	10
6	Model G-2 (K_{30} = 3.26 mil)	11
7	Model G-3 (K_{30} = 1.29 mil)	12
8	Model G-4 (10 mil)	13
9	NSWC Hypersonic Tunnel	15
10	Precooling Setup Schematic	20
11	Pitot Probe Surveys and Mach Number Profiles at Various Reynolds Numbers	25
12	Surface Roughness Characterization	27
13	Surface Traces of Model G-2 and G-3 samples	28
14	'Quick-Look' Temperature Vs. Time Plot	30
15	'Quick-Look' QDOT Vs. Thermocouple Location Along Windward Ray	31
16	'Quick-Look' QDOT Vs. Thermocouple Location Along Leeward Ray	32
17	'Quick-Look' QDOT Vs. Thermocouple Location Along Major Axis	33
18	Representative Temperature Vs. Time Plot	34
19	Representative QDOT Vs. S Plot for Ray AW	35
20	Representative H Vs. S Plot for Ray AW	36
21	P/PINF Vs. Tap Location on Ray J - Run #51	37
22	CP Vs. Tap Location on Ray N - Run #51	38

ILLUSTRATIONS (Con't)

Figure		Page
23	P/PT2 Vs. Tap Location on Ray J - Run #51.................	39
24	Shadowgraph of Model G-2 at α = 25 Degrees (Run #13)......	45
25	Shadowgraph of Model G-2 at α = 0 Degrees (Run #30).......	46

TABLES

Table		Page
1	AVCO MTSCT Test Matrix....................................	16
2	Material Properties.......................................	22
3	Mach Number Criteria......................................	24
4	Sample of Tabulated Heat-Transfer Data....................	40
5	Average Wind Tunnel Conditions and Initial Model Conditions for Run #43..	41
6	Sample of Tabulated CP Data...............................	42
7	Summary of Average Pressure Data For Run #50..............	44

INTRODUCTION

This report summarizes the results of a heat-transfer and limited pressure test series run in the Naval Surface Weapons Center/White Oak Laboratory (NSWC/WO) Hypersonic Wind Tunnel (T-8) as part of the AVCO Maneuvering Thermodynamics and Shape Change Technology (MTSCT) Program. The purpose of this wind tunnel test series was to provide data which will be utilized for verification of the AVCO MTSCT computer models. Specifically, the data generated in this test series will be used to:

a. Extend nosetip transition modeling to three-dimensional flow,

b. extend nosetip roughness heating augmentation modeling to three-dimensional flow at large roughness Reynolds number, and

c. verify/refine basic flow field models for three-dimensional nosetip configurations.

MODELS AND INSTRUMENTATION

Three models were supplied by AVCO and instrumented at the Naval Surface Weapons Center. All nosetip models were oblate spheriod shapes (5.0" major axis) with an ellipticity $\varepsilon = 1/2$. The model size for the 2:1 elliptical shapes was selected to provide natural transition on the smooth wall model at the maximum test Reynolds number. The test models were fabricated from wrought nickel with a nominal thickness of 0.060-inch. Model layout and sting adapter are shown in Figure 1.

Two models were instrumented with 112 chromel-alumel thermocouples of 5-mil-wire diameter. The wires were fused into a bead of approximately 1/32-inch-diameter and then spot welded to the interior surface of the model. Model G-1 was a highly polished model with a surface roughness < 0.01 mils. The second model (G-2) was grit blasted at NSWC to a surface roughness of $\bar{K}_{30} = 3.26$ mils. The K_{30} roughness value is a measure of surface roughness based on a 30% exceedence height and is discussed in detail later in this report. After model G-1 was tested, it was grit blasted to a $K_{30} = 1.29$-mil roughness and then identified as model G-3. Model G-4 (10-mil-brazed roughness) instrumentation consisted of 67 chromel-alumel thermocouples and 31 Statham pressure transducers. The pressure transducers were housed in an external pressure bank outside of the test cell. Twelve feet of 3/32-inch O.D. stainless steel tubing was required to connect each Statham transducer to the respective model port. Number 51 holes (.067-inch-diameter) were drilled by AVCO at the desired locations. The holes were then tapped with a 3-56 thread. This resulted in about four threads in the .060-inch model wall. Small lengths (less than four inches) of the 3/32-inch tubing were then screwed into the tapped holes until they were flush with the model surface. Loctite was then used to seal the threads. Finally, as an "insurance policy" to prevent leakage, RTV silicone rubber was placed at the tube/model interior surface junction. Approximately one foot of Tygon tubing then connected the model port to the 12-foot length of tubing. A sketch of the pressure port is given in Figure 2. Pressure measurements were obtained only with the 10-mil roughness model. It was felt that the large hole size may induce boundary-layer transition

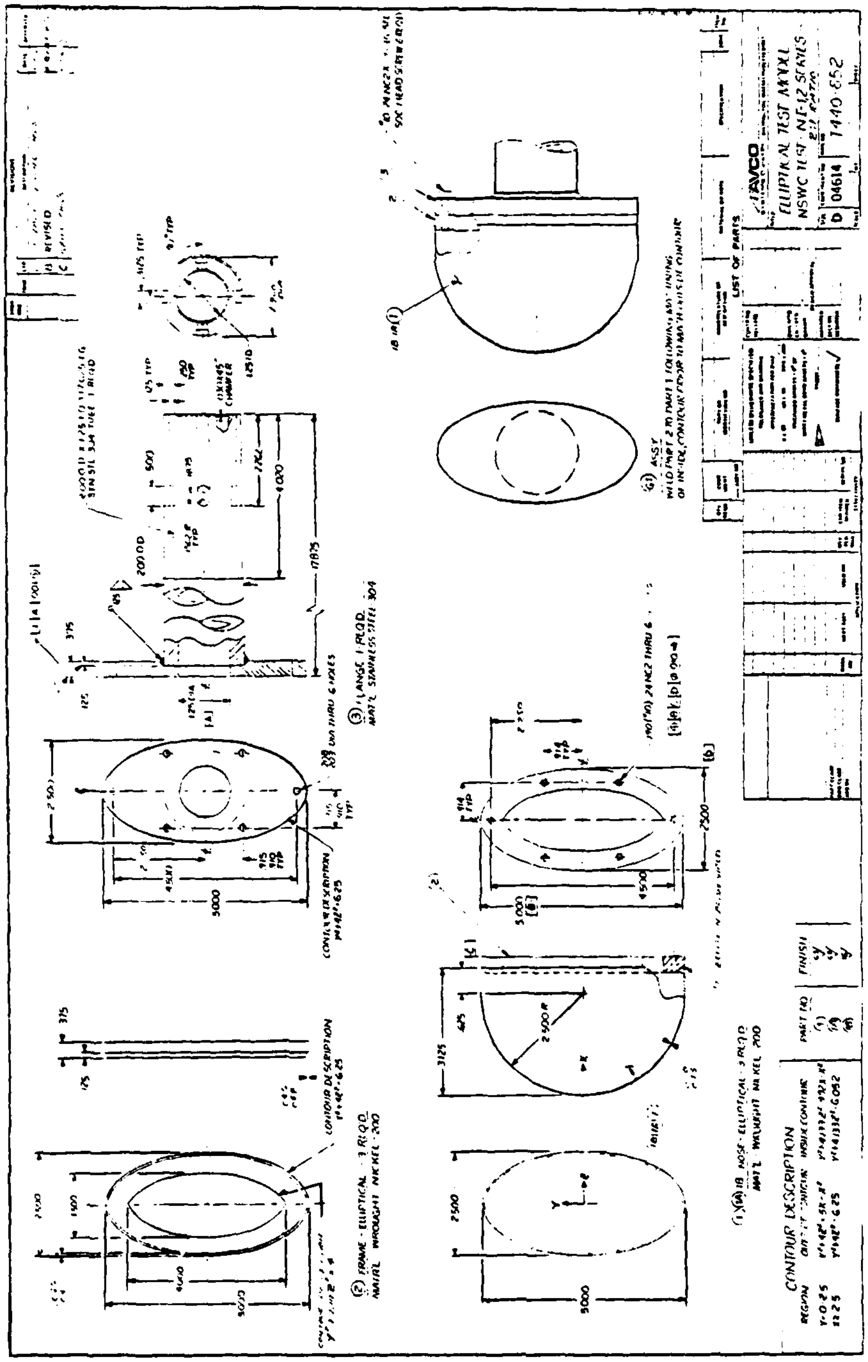


FIGURE 1 MODEL AND STING ADAPTER DRAWING

for the smooth or small roughness models, whereas for the 10-mil roughness model a fully turbulent boundary layer should already exist.

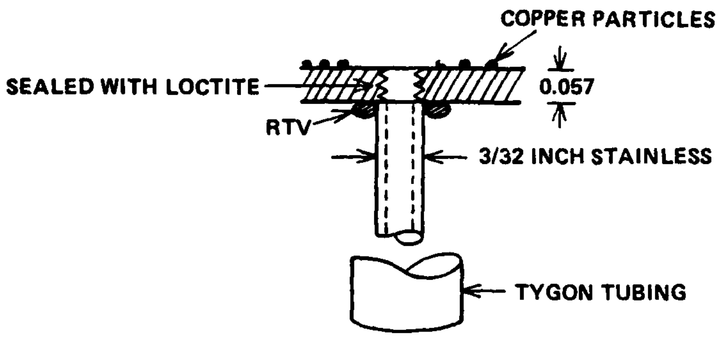
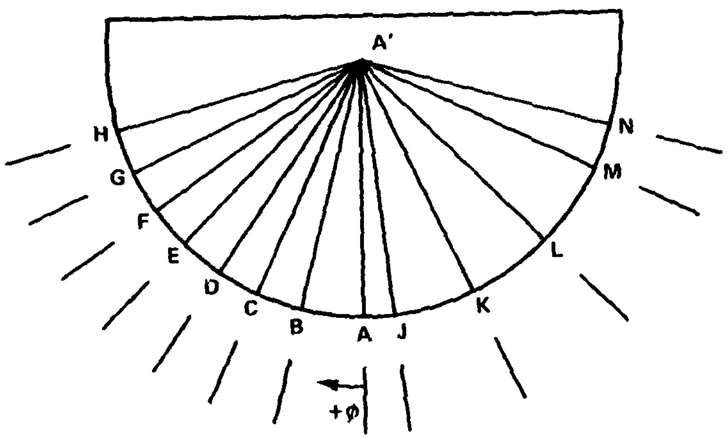


FIGURE 2 PRESSURE PORT CONNECTION

The location of the thermocouple and pressure tap coordinates are defined as the intersection of the 'radial' planes that emanate from the rotation axis of the ellipsoid (i.e., minor axis) with the semicircles centered on the rotating axis. The geometry is best visualized in Figure 3. A planform view of the model shows 'radial' planes A through H and J through N. The $\phi = 0^{o}$ ray (plane A-A') is shown to illustrate thermocouple locations. Note that for models G-1, G-2, and G-3 thermocouples are located on only half the model because of symmetry. For model G-4, pressure ports (rays J through N) are located on the other half of the model.

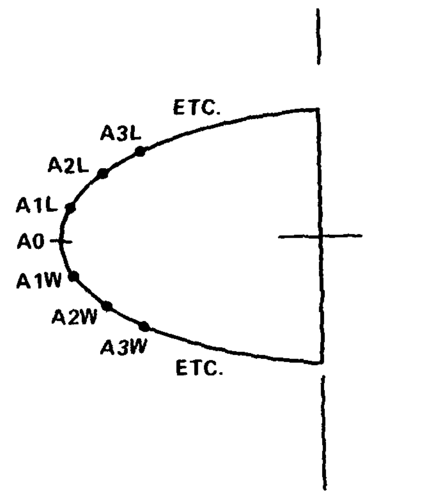
The thermocouples and pressure taps are identified by an alpha-numeric code. Thermocouples or pressure taps located at the intersection of the model surface and major axis are identified by the ray name followed by zero (two-digit code). For the remaining thermocouple and pressure taps, the meridian plane identifier is followed by the thermocouple or tap number in sequence from the 'zero' plane followed by either a 'W' (windward or bottom of model) or a 'L' (leeward or top of model). See Figure 3 for clarification.

Two views of a model in the test cell are shown in Figures 4 and 5. Figure 4 shows a top view of the G-3 model retracted into the cooling box. Figure 5 shows a side view of the G-1 model with the model oriented with the minor axis in the pitch plane ($\alpha = 0^{o}$). Photographs of the models are given in Figures 6 through 8.



PLAN VIEW

RAY	MERIDIAN (DEGREES)
A	0
B	15
C	25
D	35
E	45
F	55
G	65
H	75
J	- 6.5
K	-25
L	-45
M	-65
N	-75



SECTION A–A'

FIGURE 3 ILLUSTRATION OF THERMOCOUPLE AND PRESSURE TAP LOCATIONS

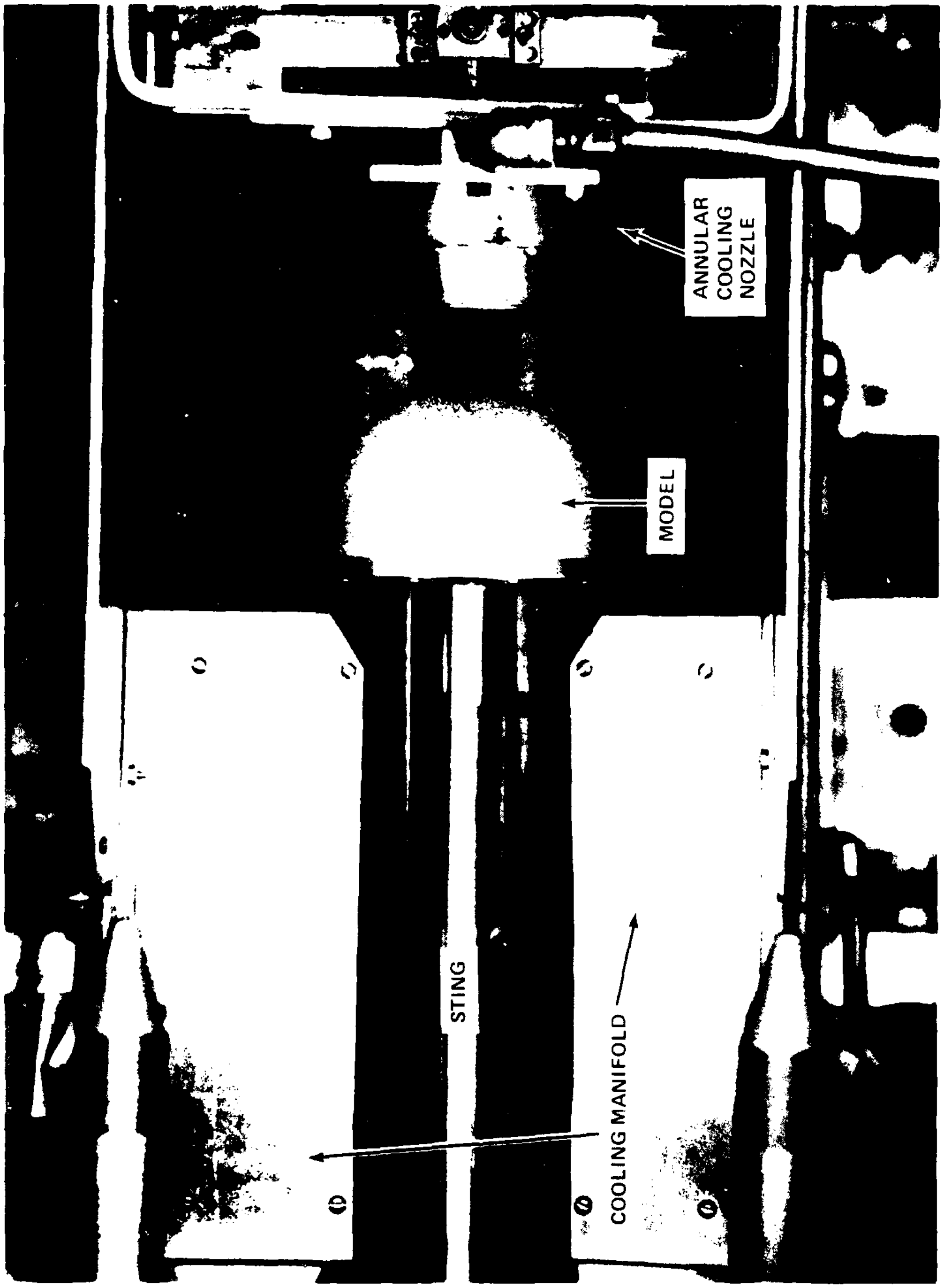


FIGURE 4 MODEL G-3 RETRACTED INTO COOLING BOX-TOP VIEW

FIGURE 5 MODEL G-1 INJECTED INTO TEST CELL-SIDE VIEW

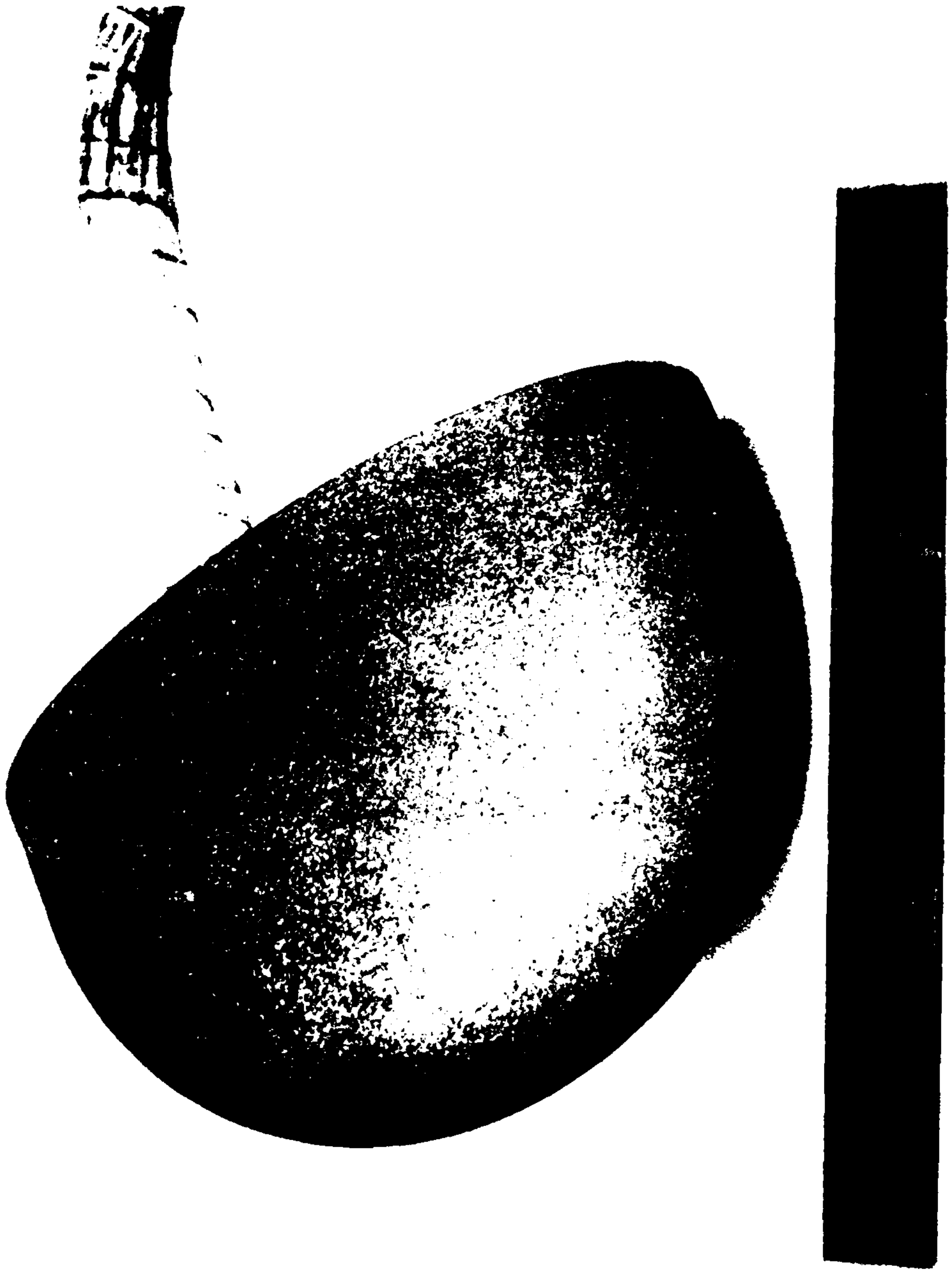


FIGURE 6 MODEL G-2 (K_{30} = 3.26 MIL)

FIGURE 7 MODEL G-3 (K_{30} 1.29 MIL)

FIGURE 8 MODEL G-4 (10 MIL)

TEST CONDITIONS

These tests were conducted in the NSWC Hypersonic Tunnel (T-8) with the axisymmetric Mach number 5 nozzle. This tunnel is a blow-down-type tunnel utilizing high-pressure air as the working medium. A line diagram of the Hypersonic Tunnel is shown in Figure 9. A more detailed description of the tunnel and its performance capability may be found in reference (1).

The tunnel Reynolds numbers were varied from 1.25×10^6 to 23.8×10^6 per foot. The test matrix with computed Reynolds numbers is given in Table 1. For most runs the model was oriented with the minor axis in the pitch plane. This was referred to as the 'wing' orientation with zero roll angle (PSI = 0). For runs #46 and #60 the model was rolled 90 degrees with the thermocouple instrumentation located on the windward side when pitched to angle of attack. For run #59 the model was rolled 180 degrees to provide leeward heat-transfer data. Data was recorded at 0, 10, and 25 degrees angle of attack.*

The enthalpy ratio (H_w/H_s) is assumed to be equal to the initial wall temperature (T_{w_i}) divided by the stagnation temperature (T_o)

$$H_w/H_s = T_{w_i}/T_o \tag{1}$$

where

$$T_o, T_{w_i} \sim {}^oR$$

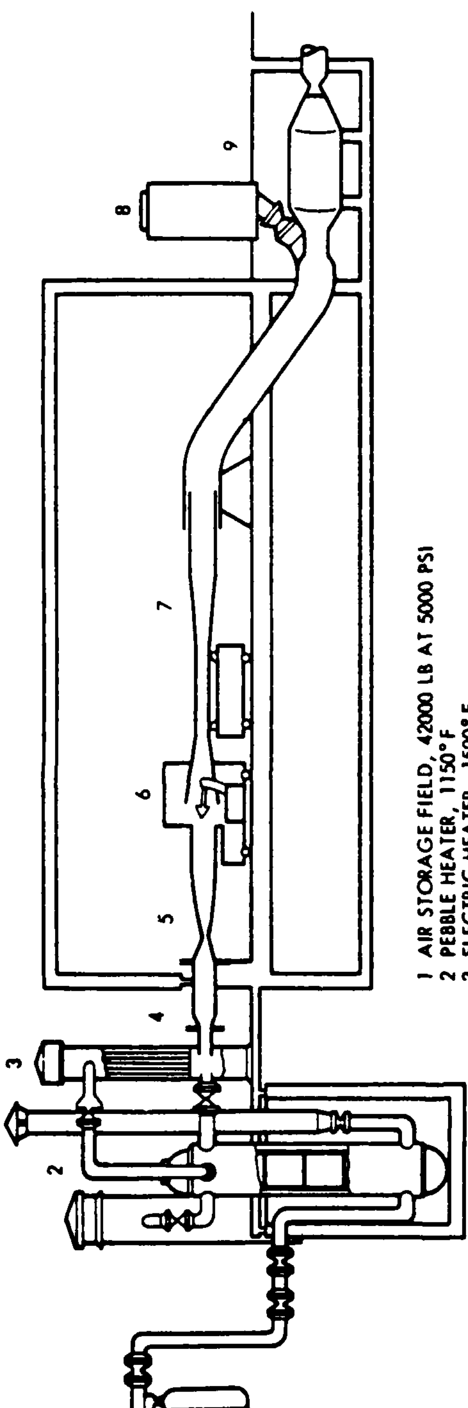
The initial wall temperature is the average temperature of all the thermocouples just prior to model injection for that particular run. The supply conditions (T_o, P_o) are averaged values over the data interval. The data interval is 0.8 seconds except for runs #49, 50, and 51. For these three runs heat-transfer and pressure data were recorded simultaneously, where the data interval for the heat transfer data is 2.0 seconds and 6.7 seconds for the pressure data.

For the 'cold-wall' enthalpy runs ($H_w/H_s = .3$) the models were precooled to a temperature as low as -150° F before injection into the test cell. The models were precooled using nitrogen and air. Liquid nitrogen was first evaporated and preheated to about -150°F. Dry air was then passed through a heat exchanger where it was cooled to approximately -100°F. The gaseous nitrogen was directed over the model from an inner annular jet of four inches in diameter. The precooled air fed into the periphery of the annular jet to provide additional cooling and to shield the model surface from any moisture in the tunnel test cell. Additionally, nitrogen was fed into the cooling box manifold to cool the sting. A schematic of the precooling setup is given in Figure 10.

---

1. Baltakis, F. P., "NSWC Hypersonic Tunnel User's Manual," NSWC/WOL MP 76-10, Jun 1976.

*For run #48, maximum angle of attack is 8.5 degrees because pitch mechanism froze due to long exposure to the cooling box.



1 AIR STORAGE FIELD, 42000 LB AT 5000 PSI
2 PEBBLE HEATER, 1150°F
3 ELECTRIC HEATER, 1500°F
4 SETTLING CHAMBER
5 NOZZLE, MACH 5-10, EXIT DIA. APPROX. 20 INCHES
6 TEST CHAMBER
7 DIFFUSER
8 EXHAUST SILENCER TO ATMOSPHERE
9 AFTERCOOLER

FIGURE 9 NSWC HYPERSONIC TUNNEL

TABLE 1 AVCO MTSCT TEST MATRIX

RUN NO.	MODEL	RE 10^6/FT	Po (PSIA)	To (^oF)	Twi (^oF)	Hw/Hs	ALPHA (Deg.)	I TIME (Sec.)	COMMENTS
1	G-1	10.50	582.6	638.0	-114.8	.301	0	2.05	
2		10.60	581.1	634.0	-111.7	.304	25	1.90	
3		15.10	870.8	717.7	-102.5	.303	0	1.82	
4		15.60	877.8	702.4	-94.1	.315	25	1.45	No Photo
5		10.40	573.0	683.8	-97.0	.317	10	1.35	No Photo
6		23.80	1202.0	622.1	89.7	.508	0	1.87	
7		23.70	1198.1	623.0	96.5	.514	25	1.70	
8		4.20	148.1	407.2	86.2	.630	25	1.85	
9		7.11	258.1	416.2	78.3	.614	25	1.92	
10		10.40	368.7	400.3	83.8	.632	25	1.87	
11	G-2	2.16	117.1	682.1	-113.2	.303	0	2.15	
12		3.12	169.3	682.6	-113.8	.303	0	2.55	
13		3.13	169.5	683.0	-108.3	.307	25	2.35	
14		2.06	108.9	666.2	-118.6	.303	25	2.37	
15		2.07	119.4	665.0	-130.2	.293	10	1.05	
16		3.26	171.1	658.4	-126.8	.298	10	1.75	
17		1.25	64.8	650.0	-128.0	.299	0	2.80	
18		1.24	63.7	641.4	-122.7	.306	10	1.92	

TABLE 1 AVCO MTSCT TEST MATRIX (CONT'D)

RUN NO.	MODEL	RE 10^6/FT	Po (PSIA)	To (^{o}F)	Twi (^{o}F)	Hw/Hs	ALPHA (Deg.)	I TIME (Sec.)	COMMENTS
19	G-2	1.25	64.3	644.8	-116.6	.311	25	1.75	
20		10.10	539.3	664.0	-109.5	.312	0	2.50	
21		10.40	540.4	644.7	-108.0	.318	25	2.07	
22		10.20	519.9	628.6	-124.1	.308	10	1.55	
23		5.01	230.0	561.8	-138.7	.314	0	2.10	
24		5.03	229.6	557.6	-150.0	.304	25	2.12	
25		5.04	238.5	553.6	-153.6	.303	10	1.90	
26		3.03	129.9	521.1	33.1	.502	0	1.72	
27		4.91	207.6	508.7	37.9	.514	0	0.25	
28		4.88	206.3	502.4	28.6	.508	10	1.75	
29		4.93	202.0	491.0	35.2	.521	25	1.60	
30		4.17	169.0	485.9	40.0	.529	0	1.62	
31	G-3	4.87	281.1	728.4	-118.1	.288	0	2.70	
32		4.86	285.1	740.4	-100.6	.299	10	4.22	
33		5.02	297.3	748.9	- 97.7	.299	25	2.17	
34		2.91	169.1	737.0	- 97.2	.303	0	2.17	
35		2.99	174.0	737.4	- 97.2	.303	10	1.97	
36		2.93	169.1	733.0	- 96.9	.304	25	1.92	
37		6.70	397.8	747.4	-102.5	.296	0	2.13	

TABLE 1 AVCO MTSCT TEST MATRIX (CONT'D)

RUN No.	MODEL	RE 10^6/FT	Po (PSIA)	To (^oF)	Twi (^oF)	Hw/Hs	ALPHA (Deg.)	I TIME (Sec.)	COMMENTS
38	G-3	6.95	410.9	746.7	- 98.8	.299	10	1.85	
39		6.95	402.2	736.4	- 92.4	.307	25	2.00	
40		7.88	451.5	722.2	-111.6	.295	0	1.62	
41		7.93	456.2	725.4	-104.9	.299	10	1.72	
42		7.87	450.6	721.8	- 96.2	.308	25	1.80	
43		11.18	611.6	686.3	125.8	.511	0	1.85	
44		11.40	622.5	685.0	136.0	.520	25	1.80	
45		9.70	523.0	668.6	-133.8	.291	0	1.75	
46		9.59	520.0	672.5	-129.8	.291	25	1.70	
47		7.90	409.6	642.9	-131.9	.297	0	1.97	$\psi=90^o$
48		7.96	411.8	641.8	-114.3	.314	8.5	2.12	$\psi=90^o$
49	G-4	4.69	148.3	345.4	29.9	.608	0	1.50	Pressure
50		4.90	152.7	338.9	38.4	.624	10	2.20	Pressure
51		4.89	152.6	338.8	58.5	.649	25	1.90	Pressure
52		9.88	481.4	596.4	74.1	.505	0	1.81	
53		9.88	481.6	596.4	86.5	.517	10	2.05	
54		10.30	498.3	593.0	89.3	.522	25	1.81	
55		10.50	561.2	663.9	-110.0	.311	25	1.93	

TABLE 1 AVCO MTSCT TEST MATRIX (CONT'D)

RUN No.	MODEL	RE 10^6/FT	Po (PSIA)	To (^oF)	Twi (^oF)	Hw/Hs	ALPHA (Deg.)	I TIME (Sec.)	COMMENTS
56	G-4	10.30	543.9	652.0	-122.7	.303	0	1.97	
57	↓	20.30	1090.5	664.8	-103.6	.317	0	1.93	
58	↓	20.00	1049.1	649.8	-103.4	.321	25	1.93	
59	↓	10.20	513.8	616.7	73.7	.496	25	2.25	$\psi=180^o$
60	↓	10.70	529.0	608.9	103.7	.527	25	1.93	$\psi=90^o$

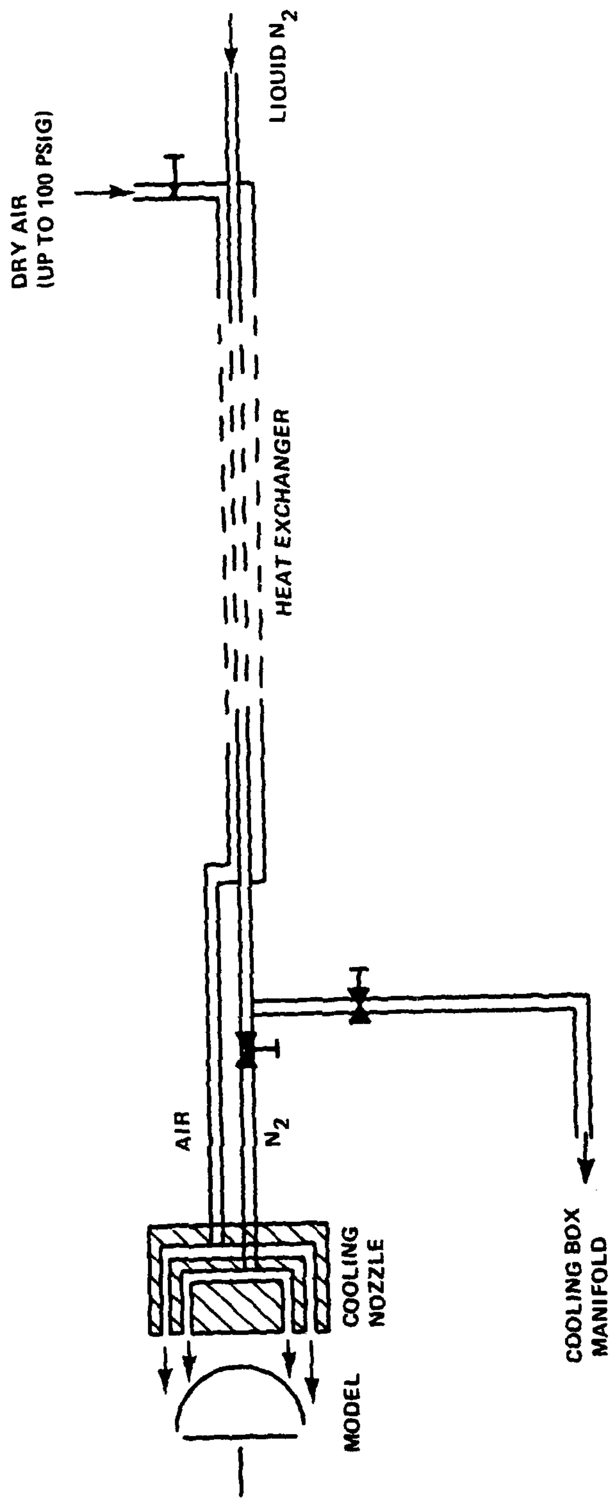


FIGURE 10 MODEL PRECOOLING SETUP FOR AVCO MTSCT T8 TEST

DATA ACQUISITION AND REDUCTION

Tunnel supply conditions and thermocouple/pressure transducer outputs are recorded on a 16-channel analog-to-digital recorder (DARE V). By multiplexing the 16 amplifiers, DARE V is capable of recording 128 inputs. For runs 49, 50, and 51 data sampling rate was ten samples per second. The low sampling rate was necessary to allow for the longer time required for the pressure measurements. For all other runs the input sampling rate was 25 samples per second.

Aerodynamic heating rates ($\dot{Q}$) and heat-transfer coefficients (H) were computed from the standard heat balance equation assuming a thin-wall model transient technique with no lateral conduction. The heat balance equation is:

$$\dot{Q} = \rho\ c\ \delta \frac{dT_w}{dt} \tag{2}$$

where

$\dot{Q}$ = heating rate (BTU/ft^2—sec)
ρ = density of the model material (lb/ft^3)
c = heat capacity of the model (BTU/lb-^{o}F)
δ = measured model wall thickness at TC location (inches)
T_w = measured wall temperature (^{o}F)
t = time (sec)

For model G-4, equation (2) is modified to account for the nonhomogenity. The equation is now written as:

$$\dot{Q} = \overline{\rho\ c\ \delta} \frac{dT_w}{dt} \tag{3}$$

where

$$\overline{\rho\ c\ \delta} = (\rho\ c\ \delta)_{Nickel} + (\rho\ c\ \delta)_{Silver\ Alloy} + (\rho\ c\ \delta)_{Copper} \tag{4}$$

The values for $(\rho c\delta)_{Silver\ Alloy}$ and $(\rho c\delta)_{Copper}$ were obtained by weighing the silver alloy and copper particles applied to the model and then computing an average thickness of the material. Average thickness values are δ_{Silver} = .0004 inches and δ_{Copper} = .0052 inches. An average model wall thickness of δ_{Nickel} = 0.057 inches was used in the data reduction program. Material properties are dependent upon the temperature and are summarized in Table 2.

TABLE 2 MATERIAL PROPERTIES

Temp. (^oR)	Density (lb/ft^3)			Specific Heat ($BTU/lb\text{-}^oF$)		
	Ni	Cu	Ag	Ni	Cu	Ag
500	555	560	655	.098	.092	.0560
750	"	"	"	.122	.096	.0570
1000	"	"	"	.133	.099	.0585
1160	"	"	"	.146	.101	.0600
1250	"	"	"	.130	.103	.0605

The temperature-time derivative values (dT_w/dt) were determined by curve-fitting the recorded temperature-time data. A second order polynomial curve fit using twenty data points was used to compute the temperature-time slope. A critical parameter in determining the heat-up rate was the initial transient or start-up time. It was necessary to choose a starting time (τ_i) for the twenty-point curve fit as close as possible to the time when the model first became fully exposed to the flow. The starting time for a particular run was determined by examining the temperature-time plots and digital data and then selecting the time when the thermocouple response became free of the model injection transients. Typically, the injection transients were between 0.1 and 0.25 seconds.

The heating rate ($\dot{Q}$) is the initial value based on the dT_w/dt value at the start of the fitted data. The heat-transfer coefficient (H) is obtained by dividing the initial heating rate by the temperature differential ($T_o - T_{w_i}$) or

$$H = \dot{Q}/(T_o - T_{w_i}) \tag{5}$$

H = heat-transfer coefficient ($BTU/ft^2\text{-sec-}^oF$)

T_o = adiabatic wall temperature (i.e., tunnel stagnation temperature, ^oF)

T_{w_i} = average initial wall temperature (^oF).

The Stanton number (St) is a nondimensional number obtained by dividing the initial heat-transfer coefficient by the freestream values of C_{p_∞}, ρ_∞, and U_∞,

$$St = \frac{H}{C_{p_\infty} \rho_\infty U_\infty} \tag{6}$$

where

C_{p_∞} = specific heat of air (0.24 $BTU/lb\text{-}^oF$)

ρ_∞ = freestream density (lb/ft^3)

U_∞ = freestream velocity (ft/sec)

The specific heat of air was assumed to be 0.24 BTU/lb-^{o}F, and the density and velocity values were computed from the tunnel air supply pressure and temperature values averaged over the curve-fitting period (typically 0.8 seconds).

Pressure data for runs 49, 50, and 51 consisted of the measured surface pressure normalized by the freestream static pressure (P/P_∞); surface pressure normalized by the total pressure behind a normal shock (P/P_{t_2}); and a non-dimensional pressure coefficient (CP). The pressure coefficient was defined as:

$$CP = \frac{P}{\rho_\infty U_\infty{}^2} \tag{7}$$

where

P = measured surface pressure (lb/ft^2)
ρ_∞ = freestream density (lb/ft^3)
U_∞ = freestream velocity (ft/sec).

The response time of the twelve feet of tubing was of concern. To reduce the response time the transducer bank was 'opened' before model injection. This produced almost a step pressure input to the flow. The pressure data was then averaged over a 6.7-second time interval.

The *tunnel Reynolds number was* calculated from the familiar expression:

$$RE = \frac{\rho_\infty U_\infty}{\mu} \tag{8}$$

where

RE = Reynolds number (/ft)
μ = coefficient of viscosity (lb-sec/ft2)

The coefficient of viscosity (μ) was calculated from Sutherland's formula where

$$\mu = 2.27 * 10^{-8} * \frac{T_\infty{}^{3/2}}{T_\infty + 198.6} \tag{9}$$

where

μ = coef. of viscosity (lb-sec/ft2)
T_∞ = freestream static temperature (^{o}R)

Finally, an expression that computes the required tunnel supply pressure in terms of the Reynolds number and tunnel supply temperature for the Mach number 5 nozzle is given by:

$$P_o = \frac{RE * T_o{}^2}{1.02736 \times 10^7 \ (T_o + 1.1922 \times 10^3)} \tag{10}$$

where

P_o = supply pressure (psi)
T_o = supply temperature (^oR)
RE = desired tunnel Reynolds number (per foot)

The freestream Mach numbers used in the computations were obtained from pitot probe surveys. The pitot rake surveys were taken at an axial distance of 5.5 inches from the nozzle exit plane. The pitot probe orientation and Mach number profiles at various Reynolds numbers are given in Figure 11. The criteria for the Mach number determination is summarized in Table 3. The Mach number values are based on the average of probes 2 through 5.

TABLE 3 MACH NUMBER CRITERIA

Re x 10^6/ft	Mach Number
>10	5.02
6 < Re < 10	5.01
≈5	5.00
<4	4.99

The NSWC 'Quick-Look' System provided reduced thermocouple data immediately following a run. Sixteen pre-selected thermocouple inputs were recorded and reduced on a 4052 Tektronix computer. Temperature-time and heating rate ($\dot{Q}$) plots were available to determine the desired Reynolds number for the next run.

SURFACE ROUGHNESS CHARACTERIZATION

Standard grit blasting techniques were used by NSWC to produce the small roughness on models G-2 and G-3. One-inch-diameter nickel samples were roughened along with the models. Photomicrograph measurements were then made on the samples to determine the surface roughness on models G-2 and G-3. In the photomicrograph method of surface roughness characterization the roughened specimen is sectioned, mounted in a room temperature setting resin for maximum edge retention, and then polished on its sectioned face to highlight the surface roughness elements. Then the sample was photomicrographed at either 50 or 100 magnification.

The approach taken in determining the surface roughness was based on roughness element height results. Polaroid photomicrographs of the sample were connected in a continuous strip. An 'arbitrary' straight line was drawn on the strip of polaroids and was defined as the reference surface (y_o). Using a seven-power calibrated eye piece, measurements from y_o to the sample surface were made at specified intervals. A probability of exceedence vs. $y-y_o$ curve was generated and a best fit straight line calculated from the data between 0.1 and 0.9 probability. By definition the 'optically apparent surface' (h_o) was the value

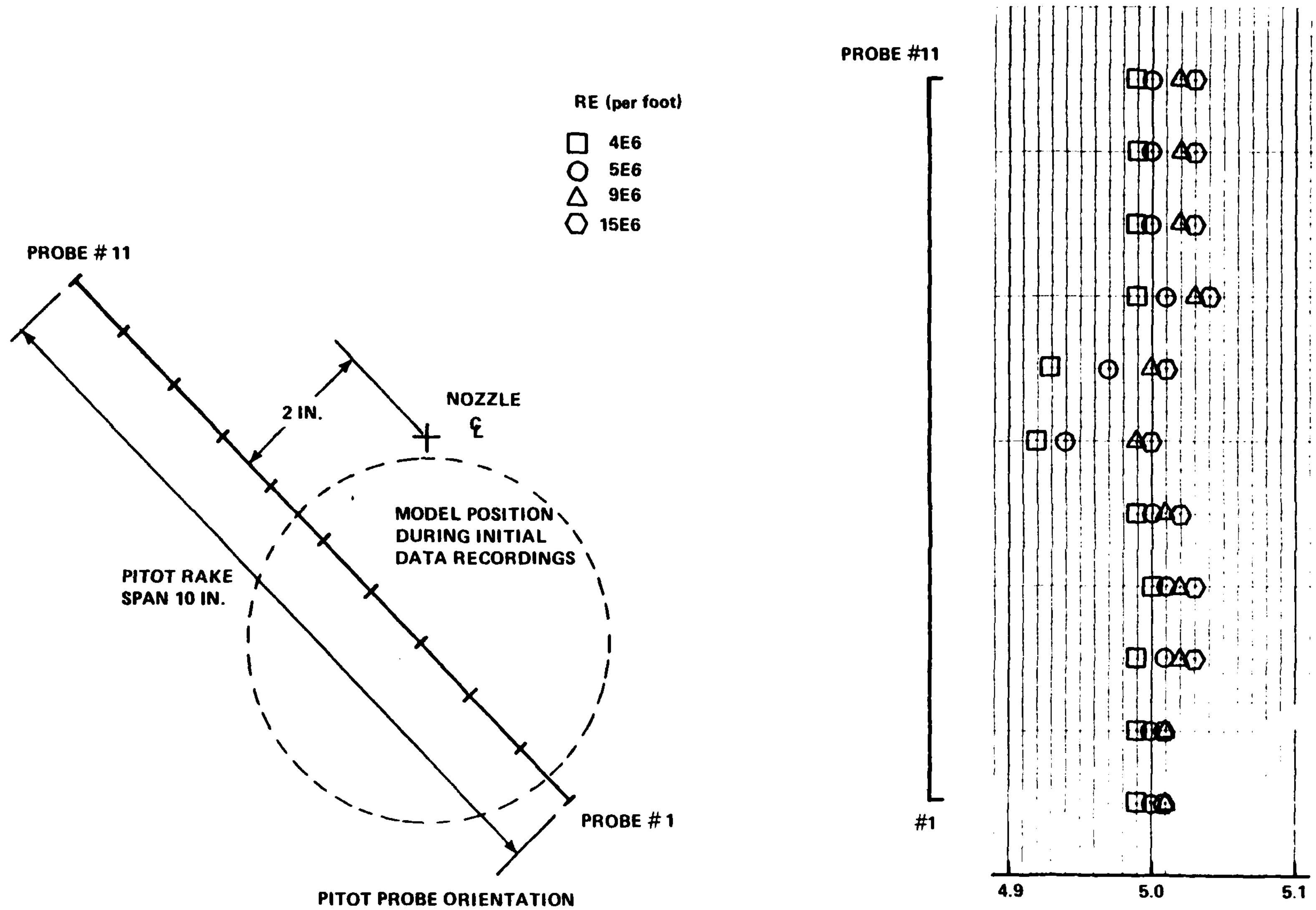


FIGURE 11 PITOT PROBE SURVEY METHOD AND MACH NUMBER PROFILES AT VARIOUS REYNOLDS NUMBERS

of $(y-y_0)$ when the probability of exceedence curve-fit equals one. Figure 12a illustrates the approach taken in defining the optically apparent reference surface (h_0) based on a tangent slope determination from the photomicrograph data. The h_0 value is an adjustment to the original reference line (y_0) and will move the reference line up $(+h_0)$ on down $(-h_0)$. The 'significant peaks' were measured from the h_0 line. A probability of exceedence vs. $(h-h_0)$ was generated for the roughness elements. It was now assumed that the 'larger' roughness elements are primarily responsible for triggering transition. Therefore, the 30 percent exceedence height (h_{30}) was chosen as the roughness value for the sample. See Figure 12b for an example. Since the plane of measurement does not pass through the peak of each roughness element, the h_{30} value is multiplied by a shape factor of $4/\pi$ (hemispherical shaped elements) to arrive at the K_{30} value.

For the 10-mil model (G-4) copper particles were brazed to the model surface in a vacuum furnace.

Prior to grit blasting the models, NSWC generated calibration curves for the grit blasting apparatus.* Nominal roughness values of K_{30} = 3.0 mil and 1.5 mil were desired for models G-2 and G-3 respectively. Calibration curves and statistical data are included in the Appendix.

Both model and sample were grit blasted for a period of time to produce uniform and complete coverage as determined by visual inspection. Typical grit blasting time was 2-3 minutes per square inch of surface area. Model G-2 and its sample were grit blasted with #12 chilled iron grit at 30 psi. The resulting surface roughness was K_{30} = 3.26 mils. The calibration curve for the G-3 model required an extrapolation to determine the lower pressure setting. A linear extrapolation was assumed and resulted in a pressure setting lower than what was required to produce the 1.5-mil roughness. Model G-3 and its sample were grit blasted at 22 psi with #25 Norton Alundum grit producing a K_{30} value of 1.29 mils. Traces of portions of the photomicrographs are given in Figure 13.

DATA FORMAT

The data generated for this wind tunnel test series included the following:

(1) 'Quick-Look' temperature-time plots and heating rates for 16 pre-selected thermocouples for each run.

(2) Digital time record of model wall temperatures.

(3) Temperature-time plots.

(4) Heat-transfer parameter values ($\dot{Q}$, H, St) in tabulated form.

(5) Plotted heat-transfer data along a given ray.

(6) Tabulated pressure data (P/P_∞, P/P_{t_2}, CP).

---

*Montgomery Ward Sand Blast Gun - Model XER-6351 modified with a 3/8-inch I.D. nozzle.

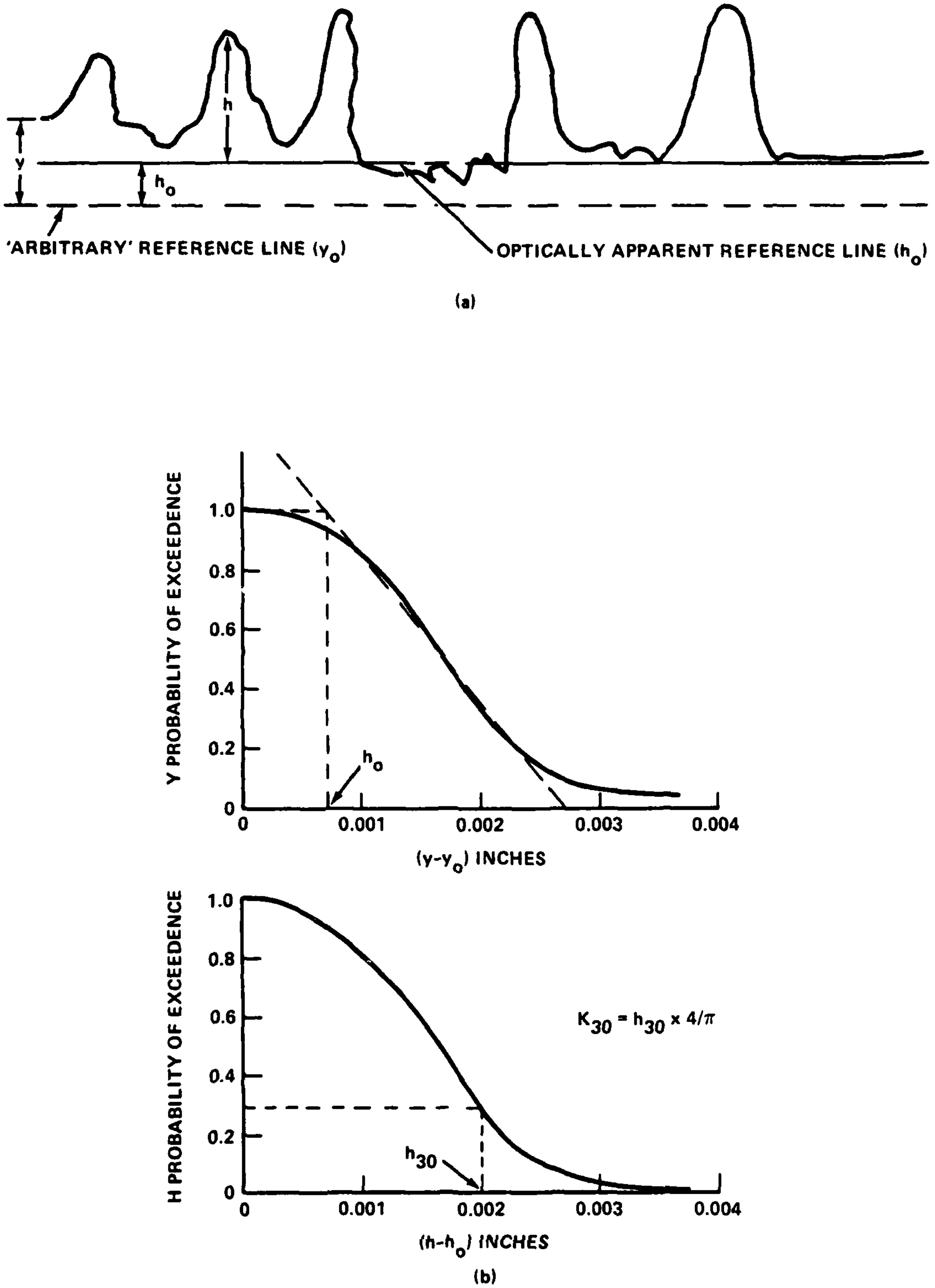


FIGURE 12 SURFACE ROUGHNESS CHARACTERIZATION AND DEFINITION

MODEL G-2 SAMPLE, 50X

MODEL G-3 SAMPLE, 100X

FIGURE 13 TRACES FROM PHOTOMICROGRAPHS

(7) Plotted pressure data along a given ray.

(8) Shadowgraph negatives and enlarged prints.

(9) Photomicrographs and surface roughness analysis.

Samples of the plotted and tabulated data are included in the report for purposes of clarification of the format and notation used. Figures 14 through 23 are representative of the plotted data, and Tables 4 through 7 are samples of the tabulated data that was transmitted to AVCO.

'Quick-Look' heat-transfer plots were available approximately five minutes following a run. From the 16 temperature-time plots the initial time to be used for the 'Quick-Look' heating rate plots were chosen. Heat-transfer rate plots consisted of Qdot versus distance along the 'A' ray from A0 for 11 thermocouples. The remaining five 'Quick-Look' thermocouples were located on the major axis. Samples of 'Quick-Look' plots are given in Figures 14 through 17.

The reduced data temperature-time plots were presented in groups of either three, four, or five thermocouples per plot. The thermocouple outputs are offset vertically by 50°F. A representative temperature-time plot is given in Figure 18.

The tabulated heat-transfer data was in the standard computer printout format and is illustrated in Table 4. The values are listed versus thermocouple number (see Figure 5 for numbering scheme). A summary page listing average initial model wall temperature and tunnel supply conditions is shown in Table 5.

The initial heating rate ($\dot{Q}$) and convective heat-transfer coefficient (H) plotted versus the distance (S) from the 'zero' thermocouple for a given ray are illustrated in Figures 19 and 20 respectively. Note that an individual plot is for thermocouple data along either the windard (W) or leeward (L) ray.

Tabulated pressure data are shown in Tables 6 and 7. Pressure measurements were taken only on runs 49, 50, and 51. Plotted pressure data for rays J and ray N on run #51 is given in Figures 21, 22, and 23.

Photographic data consists of 70-mm shadowgraphs using approximately 0.02-second exposure. The photographs were taken when the model was in the fully inserted position (i.e., at the center of the test jet). Exposure sensitivity was changed from model to model. For the smooth wall and 1.29-mil roughness models the shock shapes were of primary concern. For the 3.26- and 10-mil models, the sensitivity was increased to enhance the disturbances due to the roughness elements. Samples of enlarged shadowgraphs are shown in Figures 24 and 25.

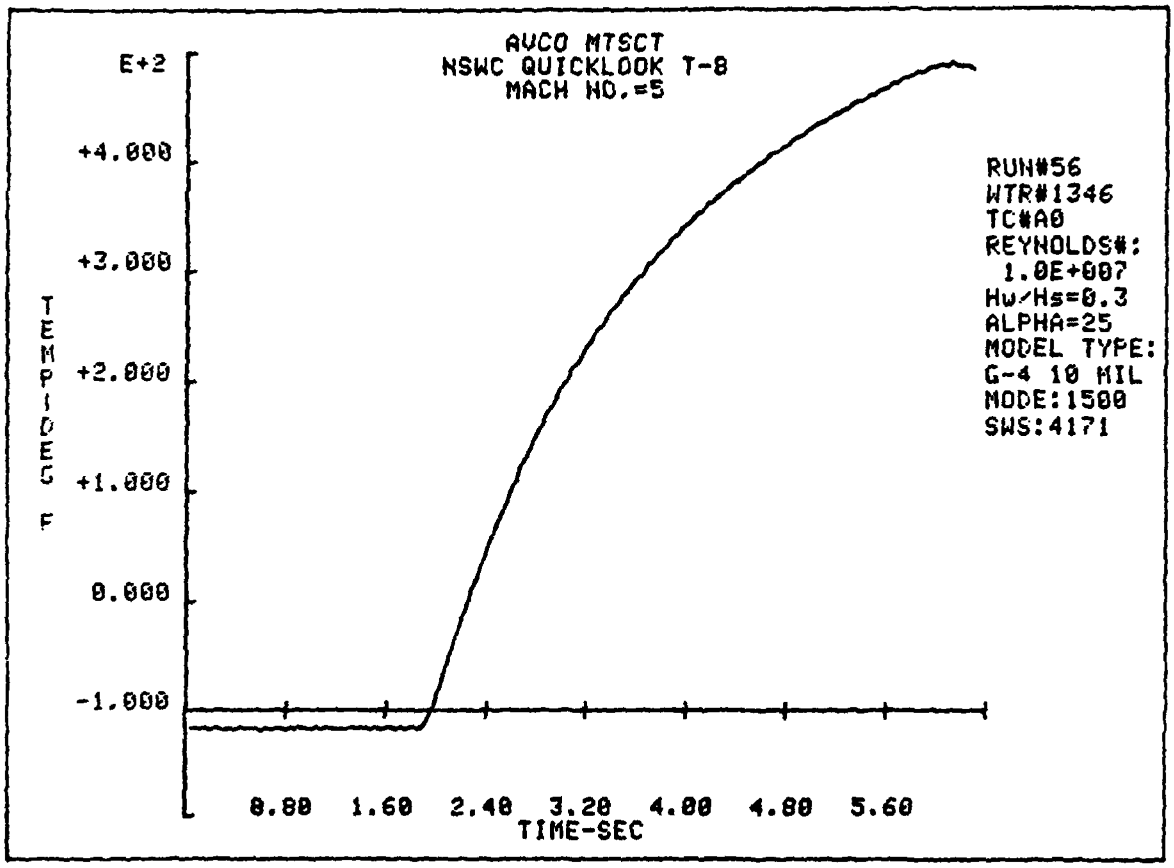


FIGURE 14 'QUICKLOOK' TEMPERATURE VS. TIME

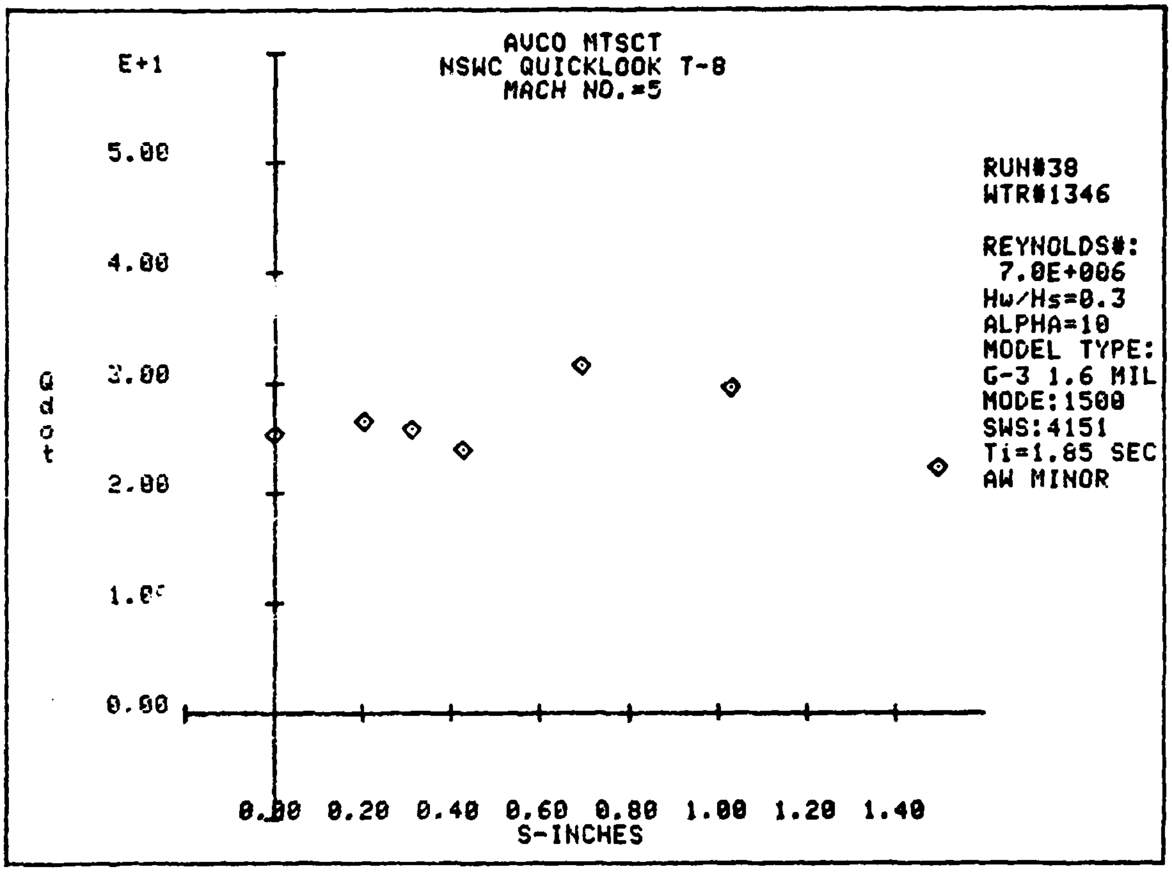


FIGURE 15 'QUICKLOOK' QDOT VS. TC LOCATION ALONG WINDWARD RAY

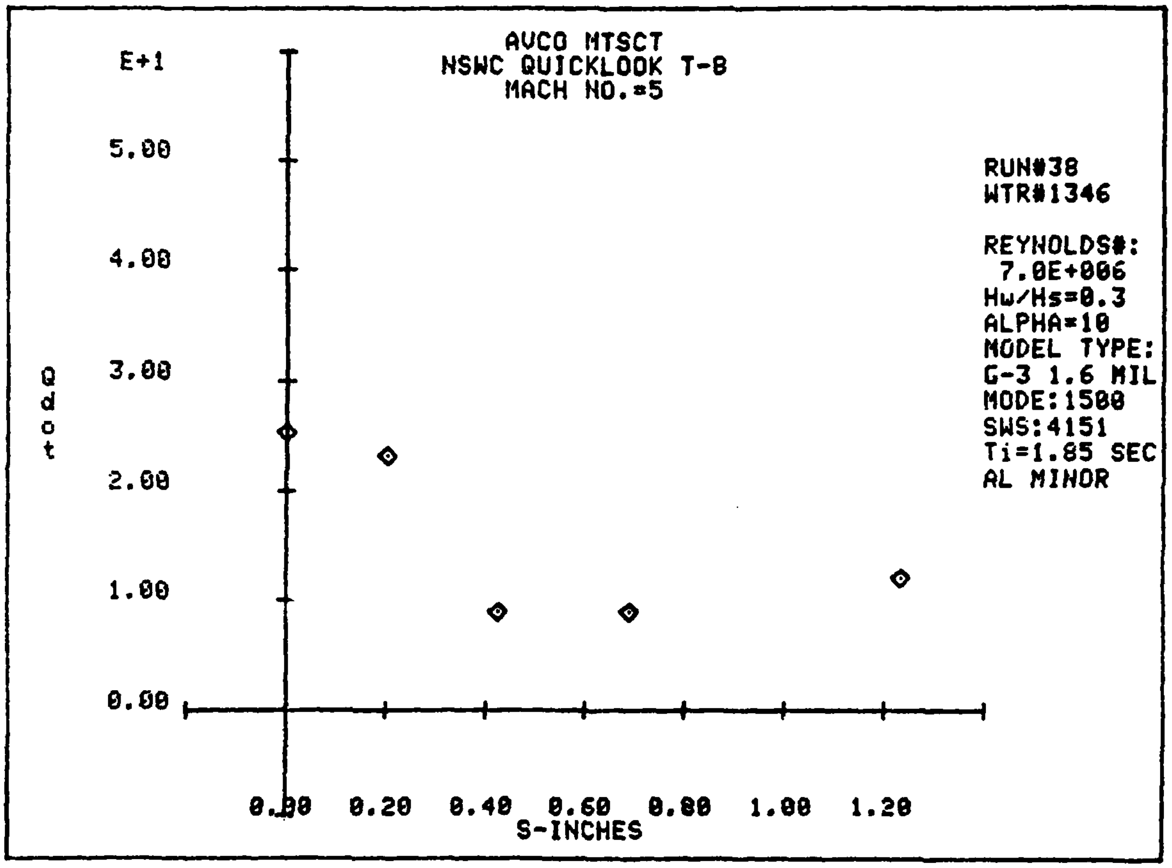


FIGURE 16 'QUICKLOOK' QDOT VS. TC LOCATION ALONG LEEWARD RAY

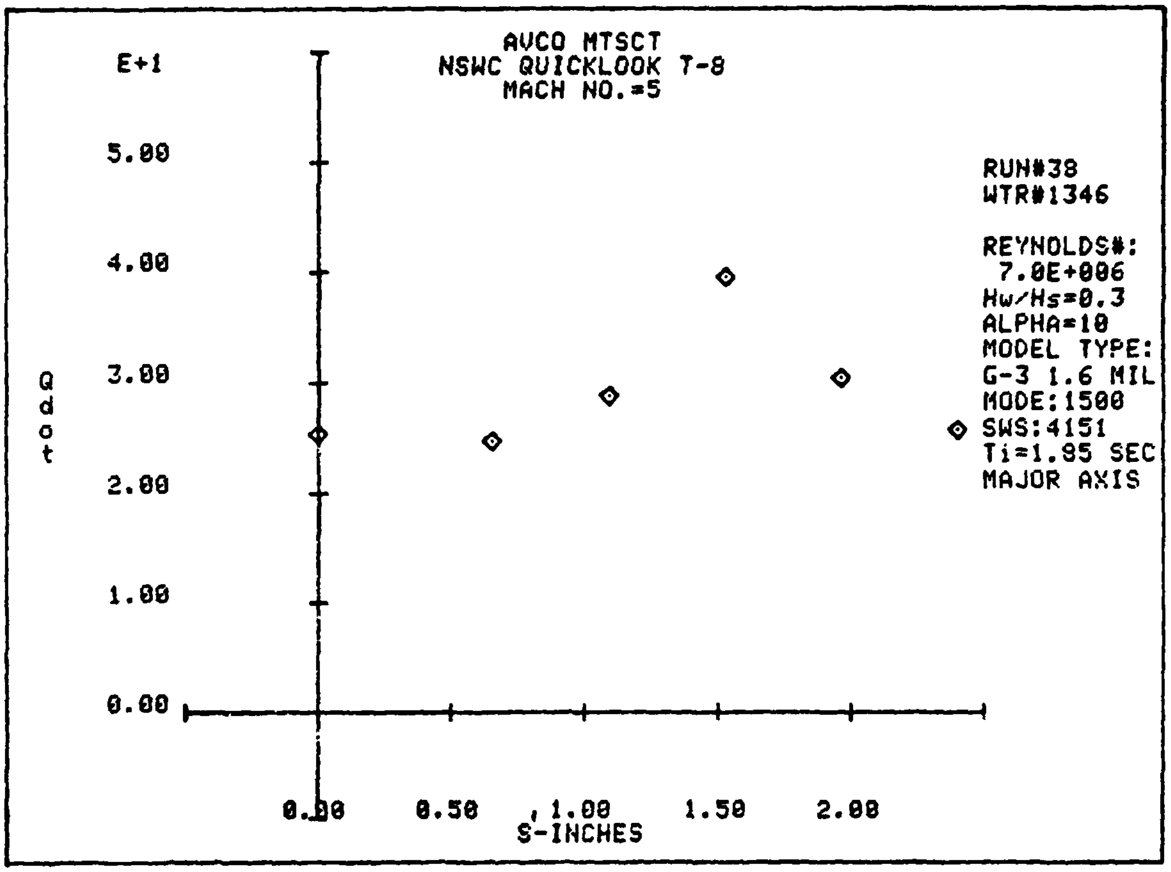


FIGURE 17 'QUICKLOOK' QDOT VS. TC LOCATION ALONG MAJOR AXIS

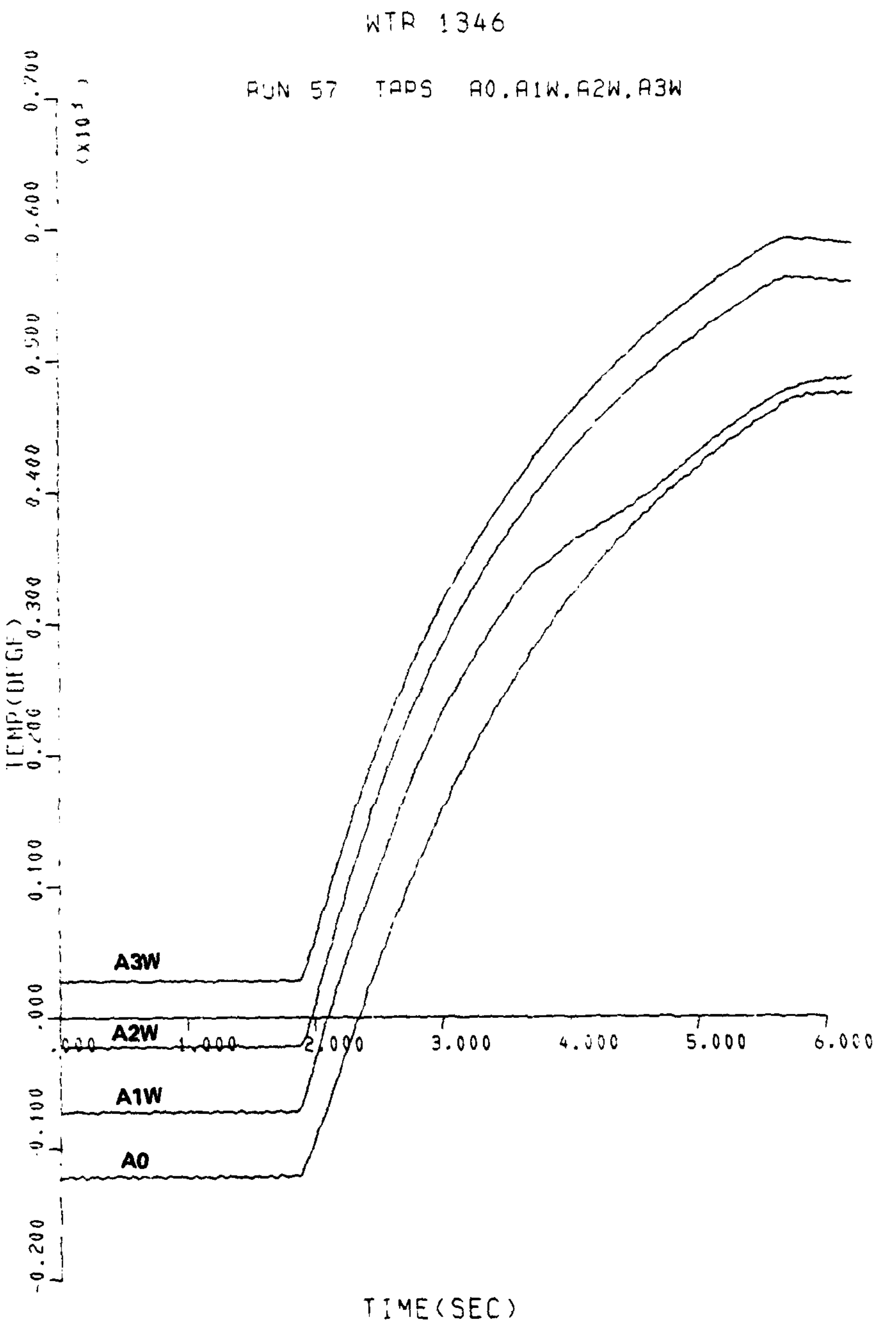


FIGURE 18 REPRESENTATIVE TEMPERATURE VS. TIME PLOT

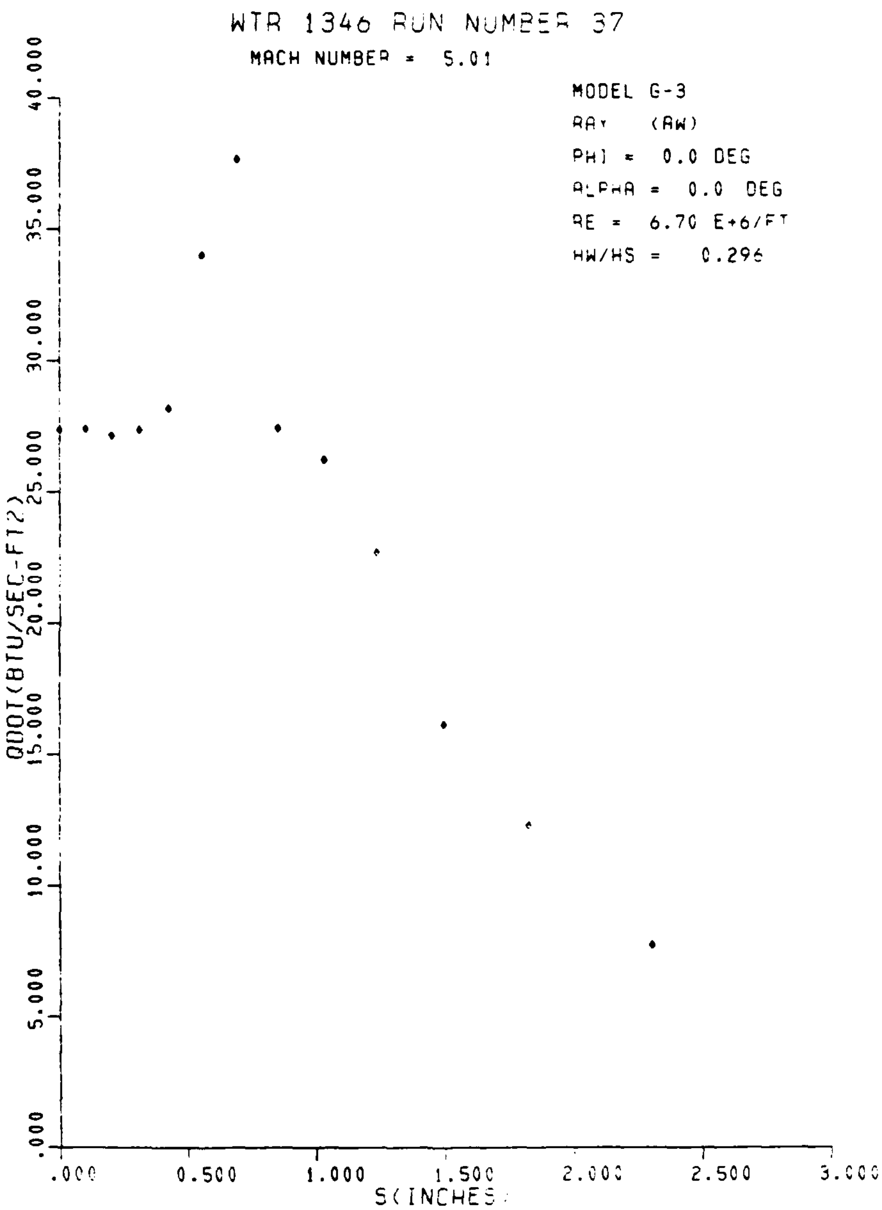


FIGURE 19 REPRESENTATIVE QDOT VS. S PLOT FOR RAY AW

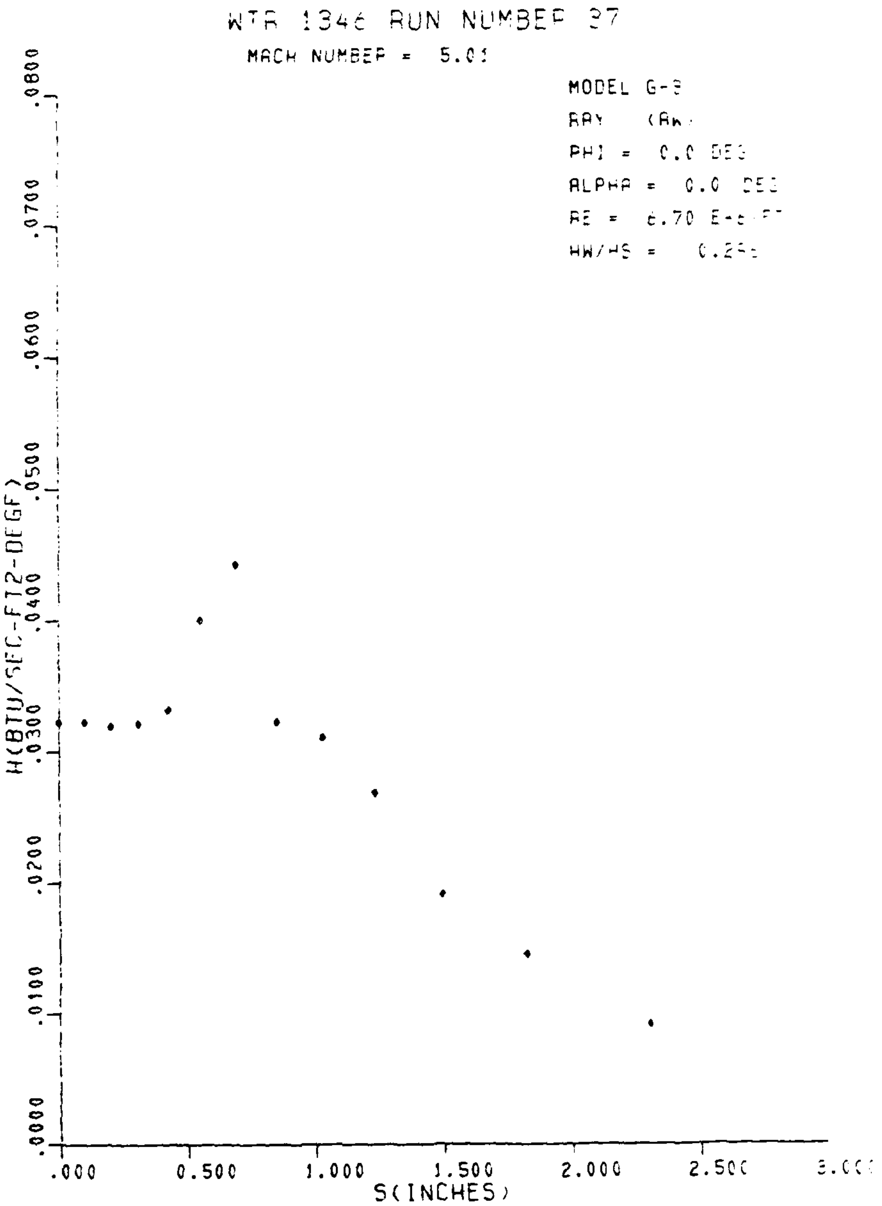


FIGURE 20 REPRESENTATIVE H VS. S PLOT FOR RAY AW

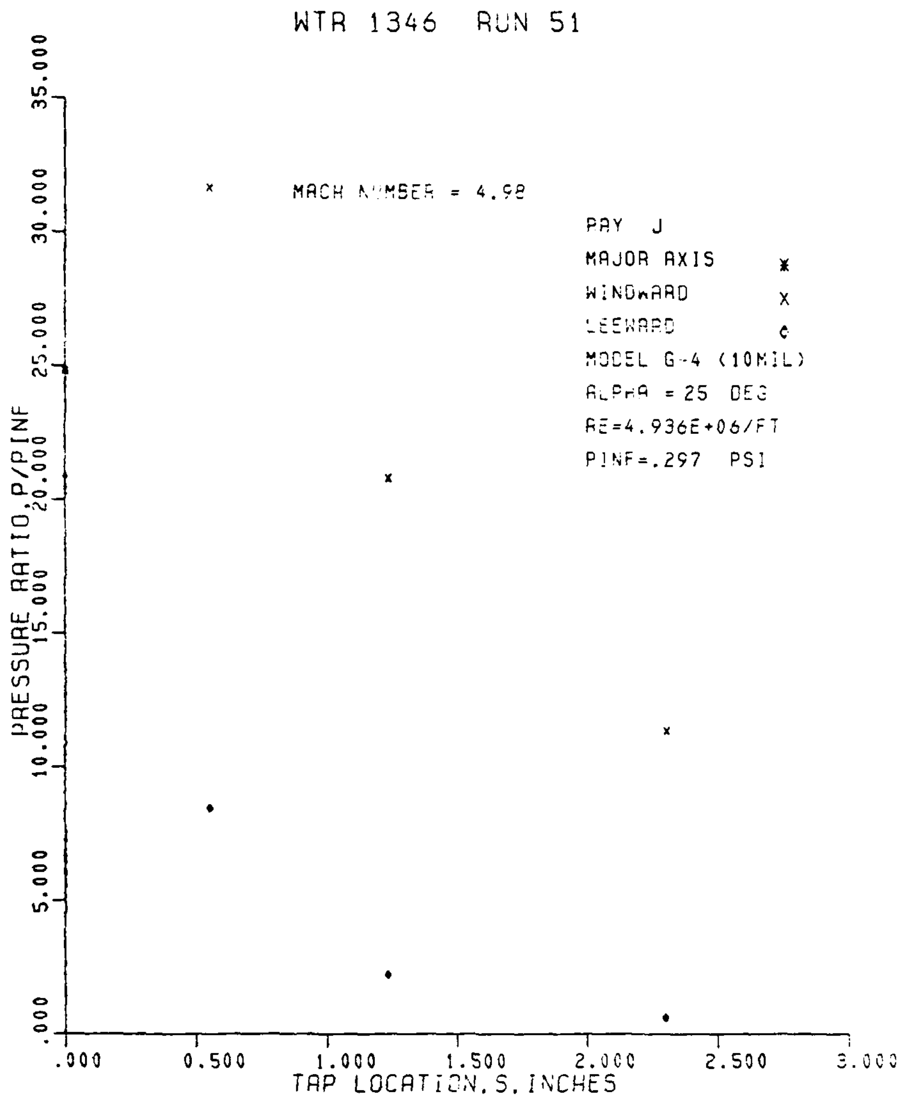


FIGURE 21 P/PINF VS. TAP LOCATION ON RAY J, RUN #51

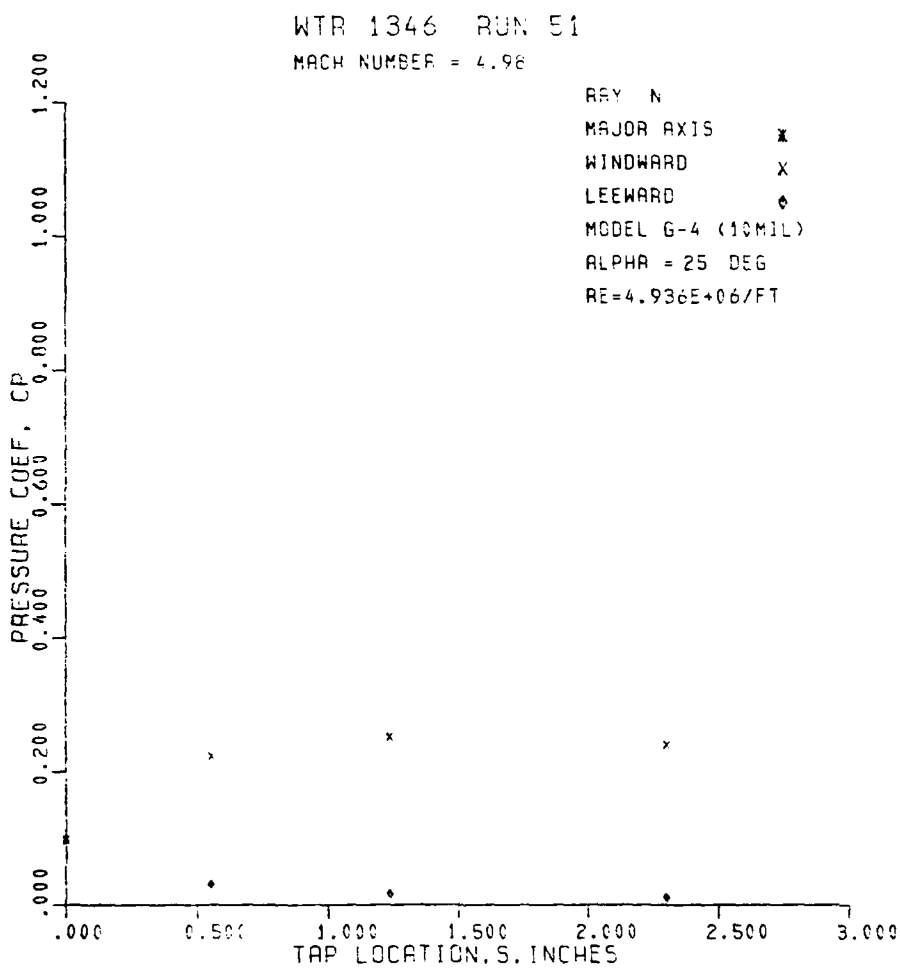


FIGURE 22 CP VS. TAP LOCATION ON RAY N, RUN #51

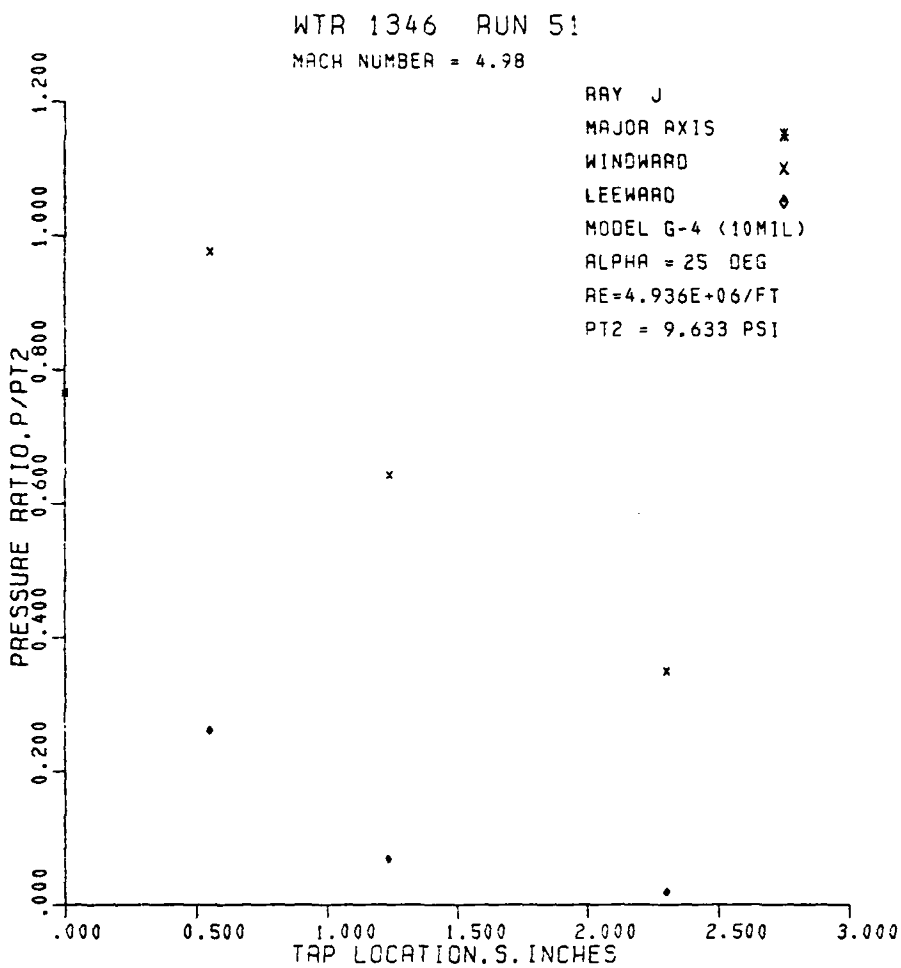


FIGURE 23 P/PT2 VS. TAP LOCATION ON RAY J, RUN #51

TABLE 4 SAMPLE OF TABULATED HEAT TRANSFER DATA

WTR 1346 RUN 43 MACH NO. 5.02 ALPHA(DEG) 0.00

DATA REDUCTION SUMMARY - FINAL H VALUE SELECTED BY METHOD 1

TC	DELTA (IN)	S (IN)	PHI DEG	TTIME (SEC)	TTMP DEGF	TW/TO	QDOT BTU/FT2-S	H BTU/FT2-S-DEGF	ST
A0	.0580	0.000	0	1.97	130.1	.515	.255E+02	.453E-01	.351E-02
A1W	.0580	.100	0	1.97	130.1	.515	.241E+02	.433E-01	.332E-02
A2W	.0580	.202	0	1.97	130.2	.515	.244E+02	.446E-01	.342E-02
A3W	.0580	.310	0	1.97	130.1	.515	.253E+02	.456E-01	.349E-02
A4W	.0580	.426	0	1.97	130.2	.515	.301E+02	.542E-01	.415E-02
A5W	.0580	.552	0	1.97	130.1	.515	.377E+02	.678E-01	.519E-02
A6W	.0580	.690	0	1.97	130.2	.515	.246E+02	.442E-01	.338E-02
A7W	.0580	.849	0	1.97	129.9	.515	.264E+02	.475E-01	.363E-02
A8W	.0580	1.030	0	1.97	129.6	.514	.243E+02	.436E-01	.334E-02
A9W	.0580	1.235	0	1.97	129.6	.514	.241E+02	.433E-01	.332E-02
A10W	.0575	1.495	0	1.97	129.6	.514	.242E+02	.435E-01	.333E-02
A11W	.0570	1.823	0	1.97	126.3	.511	.111E+02	.198E-01	.152E-02
A12W	.0570	2.303	0	1.97	123.7	.509	.704E+01	.125E-01	.957E-03

TABLE 5 AVERAGE WIND TUNNEL CONDITIONS AND INITIAL MODEL CONDITIONS FOR RUN #43

```
WTR 1340 RUN 43 MACH NO. 5.02 ALPHA(DEG) 0.00

AVERAGE WIND TUNNEL CONDITIONS

BETWEEN NSTART = 50 AND NEND = 70

PO        611.6   PSIA

TO        [illegible]   DEGF

RE/FT     .111E+08

RHO*U     54.46   LB/FT2-SEC

RHO*U*CP  47057.  BTU/FT2-HR-DEGF

MODEL AVERAGE INITIAL CONDITIONS

TWI = 125.[illegible]  DEGF

TW/TO = .511

POLYNOMIAL CURVE FIT  ORDER = 2

NUMBER OF CURVE FIT CYCLES = 1

NO. OF POINTS          NO. OF FITS

    20                     1
```

TABLE 6 SAMPLE OF TABULATED PRESSURE DATA

WTP 1346   WT 8   NSWC/WO   TODAYS DATE 81/04/27.
MODEL G-4   PRESSURE TEST   RUN 50

PO = 152.67   TO = 334.59   ALPHA = 10.0   M = 5.00   RE/L = .4937E+07/FT   PINF = .2886   QINF = 5.05

CP DATA

TIME	J0	J1W	J2W	J3W	J1I	J2I	J3L	KJ	K1W	K2W	K1I	K2L
0.00	.0032	.0028	.0028	.0032	.0029	.0035	.0031	.0035	.0028	.0128	.0035	.0035
.10	.0032	.0028	.0028	.0032	.0029	.0035	.0031	.0035	.0028	.0028	.0035	.0035
.20	.0032	.0028	.0028	.0032	.0029	.0035	.0031	.0035	.0028	.0028	.0035	.0035
.30	.0032	.0028	.0028	.0030	.0029	.0035	.0031	.0035	.0028	.0028	.0035	.0035
.40	.0032	.0028	.0028	.0032	.0029	.0035	.0031	.0035	.0028	.0028	.0035	.0035
.50	.0032	.0028	.0028	.0032	.0029	.0035	.0034	.0035	.0028	.0027	.0035	.0035
.60	.0032	.0028	.0028	.0032	.0030	.0035	.0034	.0035	.0028	.0027	.0035	.0035
.70	.0032	.0028	.0028	.0032	.0030	.0035	.0031	.0035	.0028	.0027	.0035	.0035
.80	.0032	.0028	.0028	.0029	.0030	.0035	.0031	.0035	.0028	.0027	.0035	.0032
.90	.0032	.0028	.0028	.0030	.0029	.0035	.0031	.0035	.0028	.0027	.0035	.0035
1.00	.0032	.0028	.0028	.0032	.0030	.0035	.0031	.0035	.0028	.0028	.0035	.0032
1.10	.0032	.0028	.0028	.0032	.0029	.0035	.0034	.0006	.0028	.0027	.0035	.0035
1.20	.0032	.0028	.0028	.0032	.0030	.0035	.0031	.0006	.0028	.0027	.0035	.0035
1.30	.0032	.0104	.0028	.0029	.0034	.0031	.0031	.0006	.0028	.0027	.0035	.0035
1.40	.0032	.0028	.0028	.0032	.0030	.0031	.0034	.0006	.0028	.0027	.0035	.0035
1.50	.0032	.0028	.0028	.0032	.0030	.0035	.0034	.0006	.0028	.0027	.0035	.0035
1.60	.0032	.0028	.0028	.0029	.0030	.0031	.0034	.0006	.0028	.0027	.0035	.0035
1.70	.0032	.0028	.0028	.0029	.0030	.0031	.0034	.0006	.0028	.0027	.0035	.0032
1.80	.0032	.0028	.0028	.0029	.0030	.0031	.0034	.0006	.0028	.0028	.0035	.0032
1.90	.0032	.0028	.0028	.0029	.0029	.0031	.0034	.0006	.0028	.0027	.0035	.0032
2.00	.0032	.0028	.0028	.0029	.0030	.0031	.0034	.0006	.0028	.0027	.0035	.0032
2.10	.0032	.0028	.0028	.0029	.0029	.0031	.0034	.0006	.0028	.0027	.0035	.0035
2.20	.0032	.0028	.0028	.0029	.0029	.0031	.0034	.0006	.0028	.0027	.0035	.0032
2.30	.0032	.0028	.0028	.0029	.0030	.0031	.0034	.0006	.0028	.0027	.0035	.0035
2.40	.0032	.0028	.0028	.0029	.0029	.0031	.0034	.0006	.0028	.0027	.0035	.0032
2.50	.0032	.0028	.0028	.0029	.0029	.0031	.0034	.0006	.0028	.0027	.0035	.0032
2.60	.0032	.0028	.0028	.0029	.0029	.0031	.0034	.0006	.0028	.0027	.0035	.0032
2.70	.0032	.0028	.0028	.0029	.0029	.0031	.0034	.0006	.0028	.0027	.0035	.0032
2.80	.0032	.0028	.0028	.0029	.0029	.0031	.0034	.0006	.0028	.0027	.0035	.0032
2.90	.0032	.0028	.0028	.0029	.0029	.0031	.0034	.0006	.0028	.0027	.0035	.0032
3.00	.0032	.0028	.0028	.1565	.0029	.0956	.0453	.7418	.6893	.3697	.4197	.1509
3.10	.9273	.7561	.3647	.1571	.4399	.1527	.0470	.7506	.6962	.3741	.4254	.1532
3.20	.9266	.7568	.3660	.1573	.4413	.1534	.0476	.7506	.6925	.3748	.4237	.1540
3.30	.9235	.7568	.3660	.1576	.4413	.1538	.0479	.7506	.6962	.3748	.4267	.1543
3.40	.9251	.7575	.3660	.1576	.4413	.1538	.0483	.7506	.6955	.3748	.4264	.1543
3.51	.9258	.7568	.3660	.1579	.4419	.1538	.0486	.7506	.6962	.3755	.4264	.1543
3.61	.9258	.7568	.3660	.1579	.4413	.1538	.0485	.7506	.6940	.3755	.4250	.1543
3.71	.9266	.7568	.3660	.1579	.4413	.1538	.0486	.7506	.6962	.3755	.4264	.1543
3.81	.9273	.7568	.3660	.1579	.4419	.1538	.0486	.7506	.6969	.3755	.4261	.1540
3.91	.9280	.7568	.3660	.1581	.4419	.1538	.0486	.7506	.6962	.3755	.4264	.1543
4.01	.9273	.7575	.3660	.1581	.4419	.1538	.0486	.7506	.6969	.3755	.4264	.1543
4.11	.9251	.7575	.3660	.1576	.4418	.1538	.0486	.7506	.6969	.3755	.4261	.1540
4.21	.9266	.7568	.3660	.1581	.4419	.1538	.0486	.7535	.6969	.3755	.4264	.1540
4.31	.9258	.7544	.3660	.1579	.4418	.1538	.0490	.7506	.6918	.3755	.4234	.1540
4.41	.9266	.7568	.3660	.1584	.4419	.1534	.0489	.7506	.6969	.3755	.4261	.1540
4.51	.9280	.7544	.3660	.1584	.4419	.1534	.0486	.7506	.6967	.3755	.4258	.1540
4.61	.9277	.7544	.3660	.1584	.4419	.1534	.0486	.7506	.6969	.3755	.4258	.1540
4.71	.9266	.7544	.3660	.1584	.4419	.1531	.0486	.7506	.6969	.3755	.4258	.1540
4.81	.9258	.7568	.3660	.1584	.4419	.1531	.0489	.7506	.6962	.3755	.4258	.1540
4.91	.9266	.7544	.3660	.1584	.4413	.1531	.0486	.7506	.6969	.3755	.4258	.1537

TABLE 6 SAMPLE OF TABULATED PRESSURE DATA (CONTINUED)

NTP 1346 NT 4 NSWC/WO TODAYS DATE 81/04/27.
MODEL G-4 PRESSURE TEST RUN 50

PO = 152.67 TO = 334.59 ALPHA = 10.0 M = 5.00 RE/L = .4937E+07/FT PINF = .2885 QINF = 5.050

CP DATA

TIME	J0	J1W	J2W	J3W	J1L	J2L	J3L	K0	K1W	K2W	K1L	K2L
5.01	.9266	.7544	.3660	.1584	.4418	.1531	.0486	.7506	.6969	.3743	.4258	.1535
5.11	.9266	.7544	.3649	.1584	.4404	.1531	.0485	.7506	.6947	.3755	.4244	.1540
5.21	.9273	.7538	.3656	.1587	.4404	.1531	.0485	.7506	.6947	.3743	.4247	.1535
5.31	.9273	.7544	.3649	.1584	.4404	.1531	.0486	.7506	.6969	.3743	.4258	.1535
5.41	.9273	.7544	.3649	.1587	.4404	.1531	.0486	.7506	.6969	.3751	.4258	.1535
5.51	.9258	.7538	.3660	.1587	.4418	.1531	.0485	.7506	.6947	.3743	.4247	.1535
5.61	.9266	.7544	.3667	.1584	.4413	.1531	.0486	.7506	.6969	.3743	.4254	.1535
5.71	.9273	.7544	.3649	.1584	.4413	.1531	.0486	.7506	.6969	.3743	.4258	.1535
5.81	.9273	.7551	.3649	.1584	.4404	.1531	.0485	.7506	.6947	.3751	.4244	.1535
5.91	.9244	.7544	.3656	.1587	.4413	.1531	.0488	.7506	.6954	.3751	.4247	.1535
6.01	.9251	.7551	.3649	.1587	.4413	.1531	.0485	.7506	.6947	.3751	.4247	.1535
6.11	.9280	.7544	.3649	.1584	.4413	.1531	.0488	.7506	.6947	.3751	.4247	.1535
6.21	.9280	.7544	.3649	.1587	.4413	.1531	.0489	.7506	.6969	.3751	.4261	.1535
6.31	.9251	.7544	.3649	.1587	.4413	.1531	.0485	.7506	.6947	.3743	.4244	.1535
6.41	.9244	.7544	.3649	.1587	.4413	.1531	.0497	.7506	.6846	.3751	.4184	.1535
6.51	.9273	.7551	.3649	.1584	.4413	.1527	.0488	.7506	.6947	.3751	.4247	.1535
6.61	.9244	.7551	.3649	.1587	.4413	.1531	.0488	.7506	.6947	.3751	.4247	.1535
6.71	.9251	.7551	.3660	.1584	.4427	.1527	.0488	.7506	.6947	.3751	.4247	.1535
6.81	.9244	.7544	.3649	.1587	.4413	.1531	.0488	.7506	.6947	.3751	.4244	.1535
6.91	.9229	.7544	.3649	.1587	.4413	.1531	.0488	.7506	.6947	.3751	.4247	.1535
7.01	.9244	.7551	.3649	.1587	.4413	.1527	.0488	.7506	.6947	.3751	.4247	.1535
7.11	.9244	.7544	.3656	.1582	.4413	.1527	.0488	.7506	.6947	.3751	.4247	.1535
7.21	.9273	.7551	.3656	.1582	.4413	.1531	.0485	.7506	.6947	.3751	.4247	.1535
7.31	.9258	.7544	.3656	.1582	.4413	.1527	.0485	.7506	.6947	.3751	.4247	.1535
7.41	.9244	.7551	.3649	.1587	.4413	.1527	.0485	.7506	.6947	.3751	.4250	.1535
7.51	.9236	.7551	.3656	.1582	.4413	.1527	.0485	.7506	.6947	.3751	.4247	.1535
7.61	.9244	.7575	.3660	.1579	.4427	.1527	.0485	.7506	.6947	.3751	.4247	.1535
7.71	.9251	.7544	.3649	.1582	.4413	.1527	.0485	.7506	.6947	.3751	.4250	.1535
7.81	.9236	.7575	.3649	.1582	.4413	.1527	.0485	.7506	.6947	.3751	.4247	.1535
7.91	.9244	.7551	.3649	.1582	.4413	.1522	.0488	.7482	.6947	.3762	.4247	.1540
8.01	.9244	.7544	.3649	.1582	.4413	.1527	.0485	.7506	.6947	.3762	.4244	.1540
8.11	.9244	.7544	.3649	.1579	.4413	.1522	.0485	.7482	.6954	.3762	.4247	.1540
8.21	.9236	.7544	.3649	.1582	.4413	.1527	.0485	.7506	.6947	.3762	.4247	.1540
8.31	.9244	.7544	.3649	.1582	.4413	.1522	.0485	.7482	.6954	.3762	.4247	.1546
8.41	.9244	.7544	.3649	.1582	.4413	.1527	.0485	.7506	.6947	.3751	.4250	.1535
8.51	.9258	.7551	.3656	.1579	.4413	.1522	.0485	.7482	.6947	.3762	.4247	.1546
8.61	.9287	.7544	.3649	.1582	.4413	.1522	.0486	.7482	.6976	.3751	.4264	.1535
8.71	.9251	.7551	.3656	.1582	.4413	.1522	.0485	.7482	.6954	.3751	.4250	.1535
8.81	.9251	.7544	.3656	.1582	.4413	.1522	.0486	.7482	.6969	.3758	.4264	.1535
8.91	.9287	.7551	.3644	.1582	.4401	.1522	.0486	.7482	.6976	.3758	.4264	.1535
9.01	.9280	.7568	.3656	.1582	.4413	.1522	.0485	.7482	.6947	.3751	.4247	.1535
9.11	.9266	.7544	.3656	.1582	.4413	.1522	.0488	.7482	.6954	.3770	.4250	.1540
9.21	.9287	.7551	.3656	.1582	.4413	.1522	.0486	.7482	.6976	.3770	.4264	.1540
9.31	.9280	.7575	.3656	.1582	.4413	.1526	.0489	.7482	.6969	.3758	.4264	.1535
9.41	.9280	.7544	.3644	.1582	.4401	.1522	.0486	.7482	.6976	.3751	.4264	.1538
9.51	.9280	.7544	.3644	.1582	.4401	.1526	.0486	.7482	.6976	.3762	.4267	.1543
9.61	.9273	.7544	.3656	.1582	.4413	.1522	.0486	.7482	.6969	.3770	.4264	.1540
9.71	.9280	.7551	.3644	.1582	.4403	.1526	.0486	.7482	.6976	.3770	.4264	.1543
9.81	.9273	.7568	.3644	.1582	.4401	.1526	.0486	.7511	.6976	.3758	.4267	.1535
9.91	.9266	.7551	.3661	.1579	.4401	.1526	.0486	.7482	.6976	.3758	.4273	.1535

TABLE 7 SUMMARY OF AVERAGE PRESSURE DATA FOR RUN #50

NTO 1366 — HT 4 — NSWC/WO — TODAYS DATE 81/04/17.
MODEL G-6 — PRESSURE TEST — RUN 50

PO = 152.67 — TO = 334.59 — ALPHA = 16.0 — M = 5.30 — RE/L = .4937E+07/FT — PINF = .2886 — VINF = 5.655

AVERAGE DATA

	J0	J1W	J2W	J3W	J1L	J2L	J3L	K0	K1W	K2W	K1L	K2L
P/PINF	32.4139	26.4238	12.7873	5.5772	15.4167	4.7475	1.7012	26.2351	24.3449	11.1410	14.8837	5.3906
CP	.9261	.7550	.3652	.1582	.4411	.1328	.0496	.7496	.6957	.3755	.4254	.1537
P/PT2	.9926	.8092	.3916	.1696	.4728	.1639	.0521	.8034	.7456	.4024	.4553	.1648

	L0	L1W	L2W	L3W	L1L	L2L	L3L	M0	M1W	M2W	M1L	M2L
P/PINF	14.6519	12.4755	9.3384	6.0274	7.9[illegible]	3.0960	1.3626	6.1641	7.3342	5.6036	3.4357	1.8291
CP	.4141	.3564	.2660	.172[illegible]	.22[illegible]	.0885	.0389	.1761	.2387	.1601	.0973	.0523
P/PT2	.4478	.3920	.2950	.1945	.2336	.0949	.0417	.1888	.2237	.1716	.1043	.0560

	N0	N1W	N2W	N3W	N1L	N2L	N3L
P/PINF	3.5444	5.1351	4.6247	3.7411	2.2771	1.4575	1.1340
CP	.1017	.1467	.1256	.1059	.0551	.0416	.0315
P/PT2	.1085	.1573	.1365	.1146	.0593	.0446	.0338

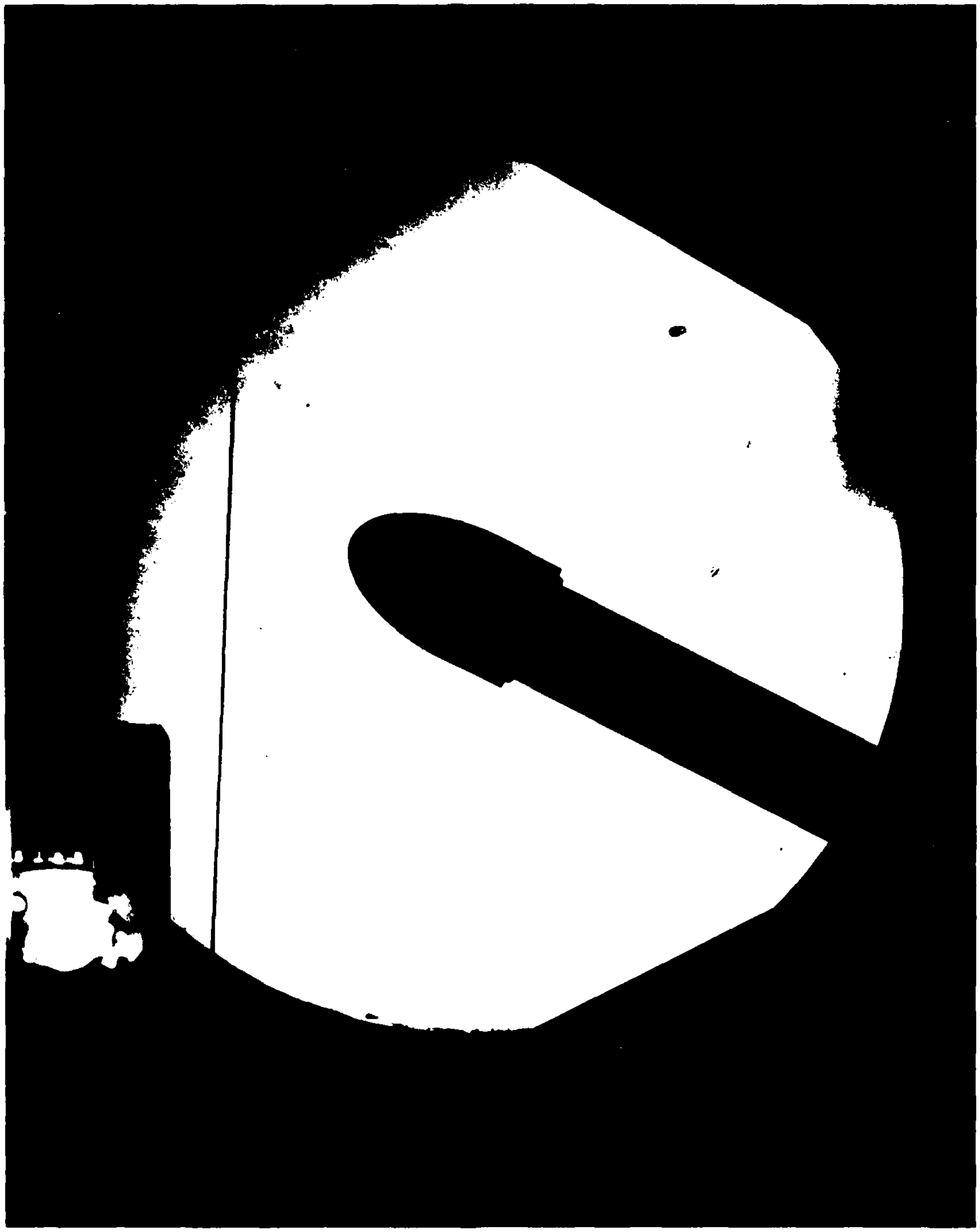


FIGURE 24 SHADOW GRAPH OF MODEL G-2 AT α 25 DEGREES, RUN #13

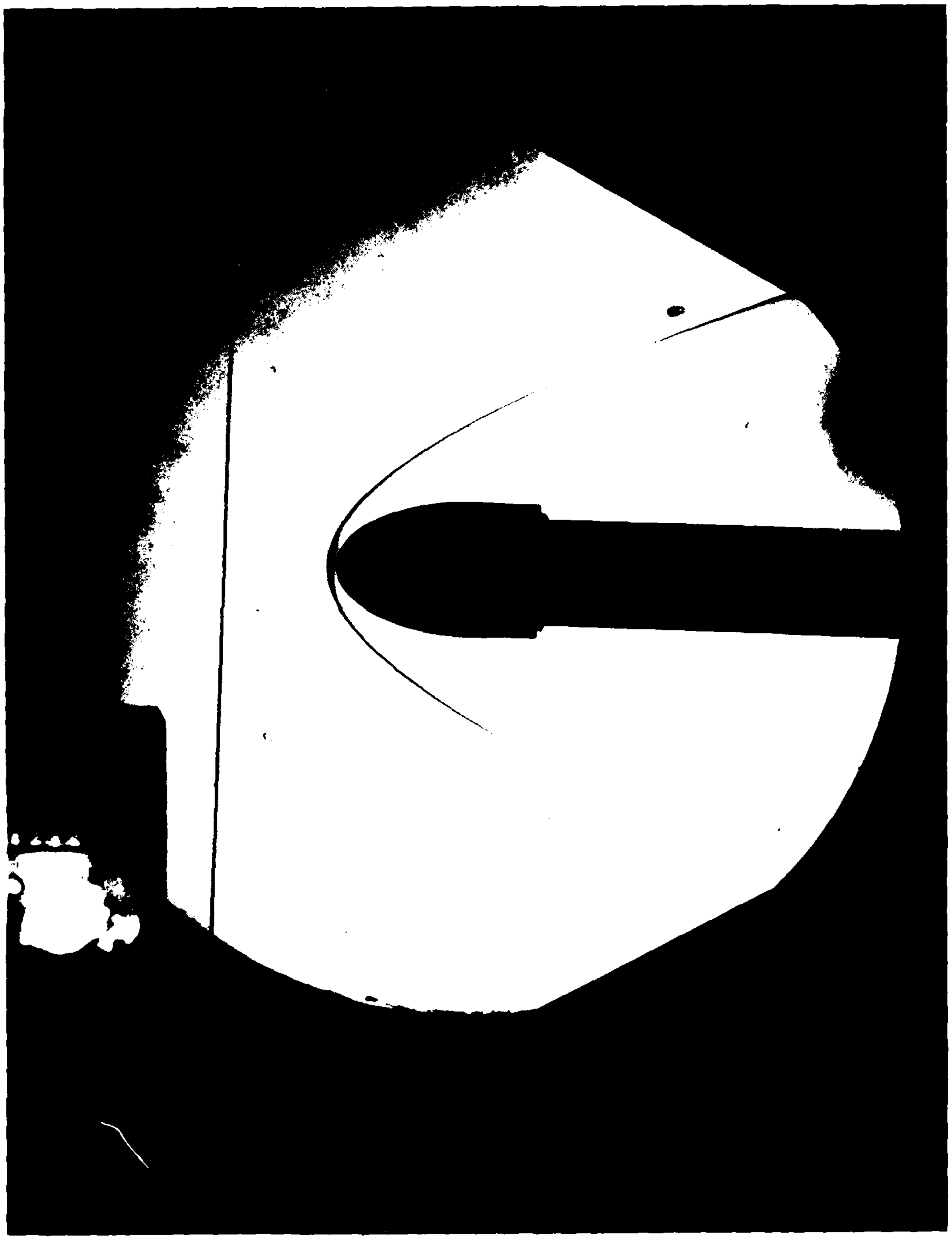


FIGURE 25 SHADOW GRAPH OF MODEL G-2 AT α 0 DEGREES, RUN =30

BIBLIOGRAPHY

Baltakis, F. P., "NSWC Hypersonic Tunnel User's Manual," NSWC/WOL MP 76-10, Jun 1976.

Baltakis, F. P., "Wind Tunnel Study of Weather Cratering Effects on Nosetip Transition," NSWC, Strategic Systems Dept, Dec 1980.

Batt, R. G. and Legner, H. H., "A Review of Roughness Induced Nosetip Transition," AIAA Paper 81-1223, Jun 1981.

"NACA Report 1135, Equations, Tables and Charts for Compressible Flow," Ames Research Staff, 1953.

"Pretest Letter Report for MTSCT Test Series NI-1 and NI-2," AVCO Systems Division, Wilmington, MA, 15 Nov 1980.

NOMENCLATURE

Alpha, α	Angle of attack (degrees)
C	Heat capacity (BTU/lb-^{o}F)
C_{p_∞}	Heat capacity of air (.24 BTU/lb-^{o}F)
CP	Pressure coefficient
Delta, δ	Model wall thickness (inches)
Ellipticity, ε	Ratio of minor to major axis
h	Roughness element height measured from h_o (mm)
h_o	Optically apparent reference surface (mm)
h_{30}	30% probability of exceedence height (mils)
H	Heat-transfer coefficient (BTU/ft^2-sec-^{o}F)
H_s	Tunnel stagnation enthalpy
H_w	Initial model wall enthalpy
ITIME, τ_i	Time at which data curve fit begins (seconds)
ITMP	Initial model wall temperature (^{o}F)
K_{30}	Surface roughness value (mils)
M_∞	Freestream Mach number
mm	Millimeter
mils	One-thousandths of an inch
P	Measured surface pressure (lb/ft^2)
P_o	Tunnel supply pressure (psia)
Phi, ϕ	Meridian ray angle (degrees)

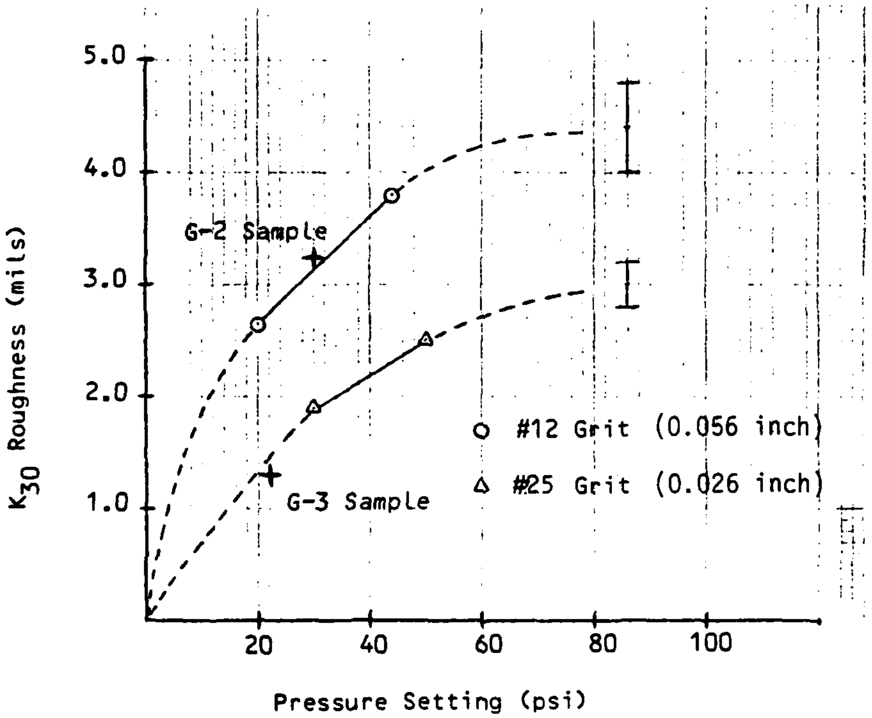
NOMENCLATURE (Con't)

PINF, P_∞	Freestream static pressure (psia)
Psi, ψ	Model roll orientation (degrees)
P_{t_2}	Total pressure behind normal shock (psia)
QDOT, $\dot{Q}$	Heat-transfer rate (BTU/ft^2-sec)
RE	Reynolds number (per foot)
S	TC or tap location measured from intersection of major axis and model surface (inches)
St	Stanton number
t	Time (seconds)
T_∞	Freestream static temperature (^{o}F)
T_o	Tunnel supply temperature (^{o}F, ^{o}R)
T_w	Measured wall temperature (^{o}F)
T_{w_i}	Initial wall temperature (^{o}R)
TC	Thermocouple
U_∞	Freestream velocity (ft/sec)
y	Distance from y_o to roughness sample surface (mm)
y_o	Arbitrary straight line on photomicrograph
μ	Coefficient of viscosity (lb-sec/ft^2)
ρ	Density of model material (lb/ft^3)
ρ_∞	Freestream density (lb/ft^3)

APPENDIX A

SURFACE ROUGHNESS CHARACTERIZATION

A. Calibration Curves -- NSWC Sand Blast Apparatus
Material -- Nickel 200



Sample	Pressure Setting (psi)	K_{30}(mils)	$\bar{h}$(mils)	$\tilde{h}$(mils)
G-2	30	3.26	2.81	3.18
G-3	22	1.29	1.07	1.17

$$K_{30} = h_{30} \times \frac{1}{M} \times \frac{4}{\pi}$$

where M = magnification
$4/\pi$ = shape factor

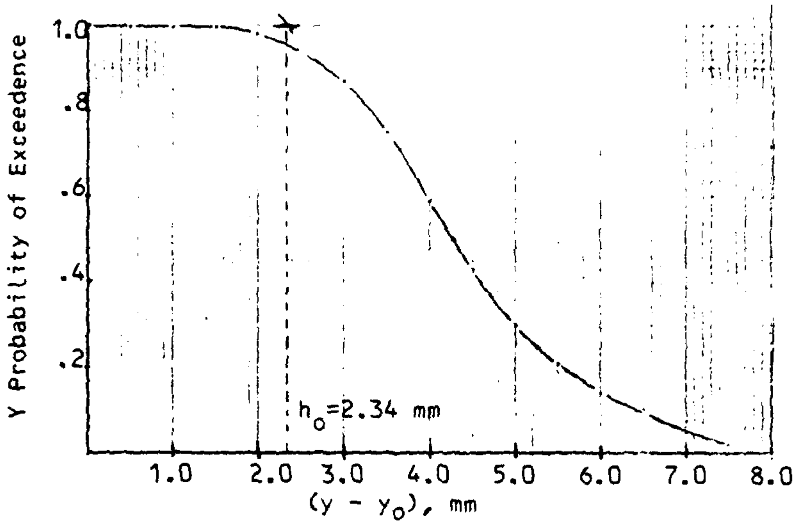
$$\bar{h} = (h-h_o)_{avg} = \frac{1}{n}\sum_1^n (h-h_o) \times \frac{4}{\pi}$$

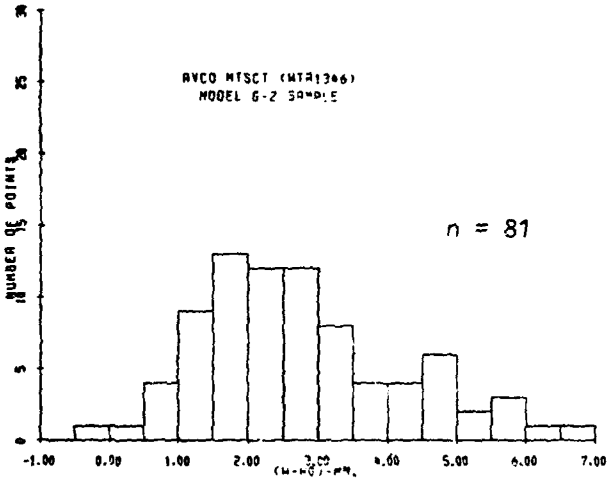
$$\tilde{h} = (h-h_o)_{rms} = \left[\frac{1}{n}\sum_1^n (h_i-\bar{h})^2\right]^{1/2} \times \frac{4}{\pi}$$

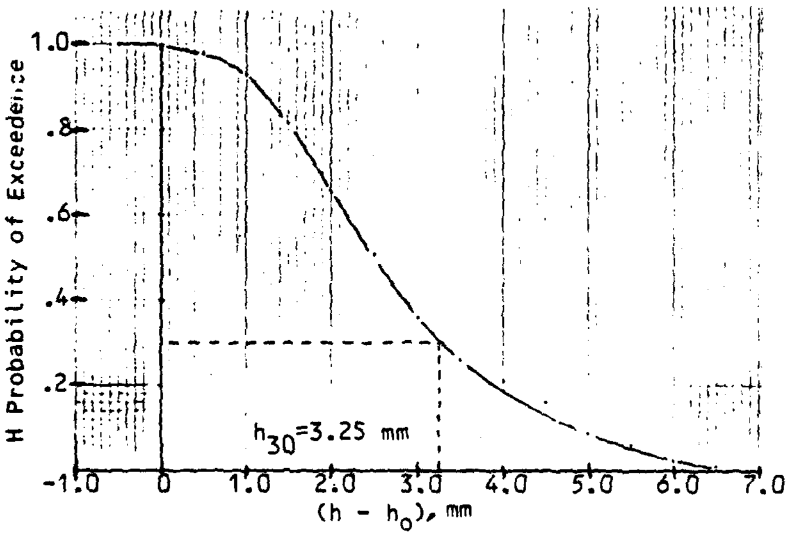
where n = number of data points

APPENDIX A (CON'D)

B. PHOTOMICROGRAPHY DATA G-2 SAMPLE

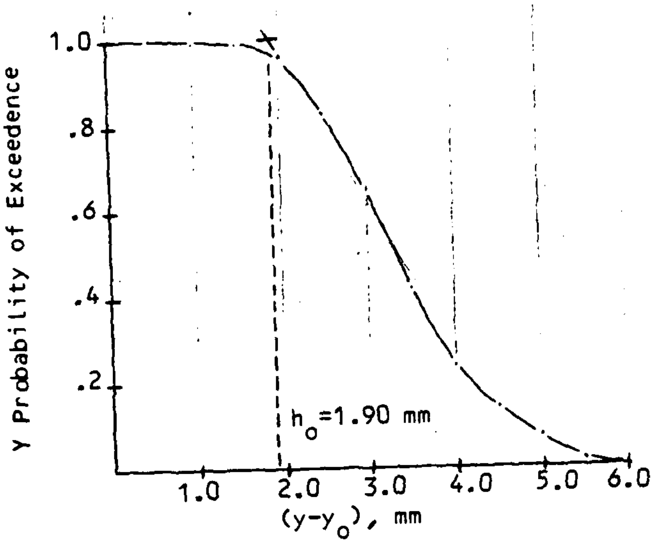

1.0
.8
.6
.4
.2
Y Probability of Exceedence
h0=2.34 mm
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0
(y - y0), mm

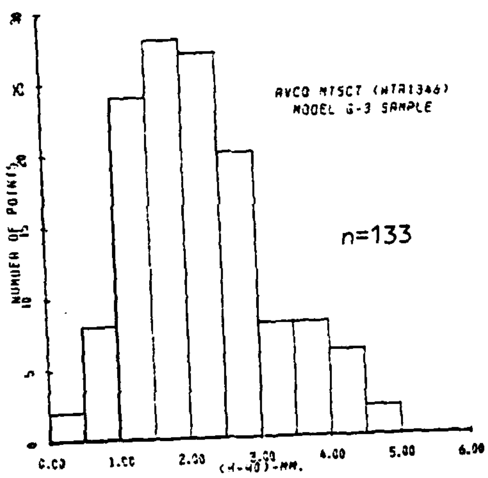

NUMBER OF POINTS
n = 81
-1.00 0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00

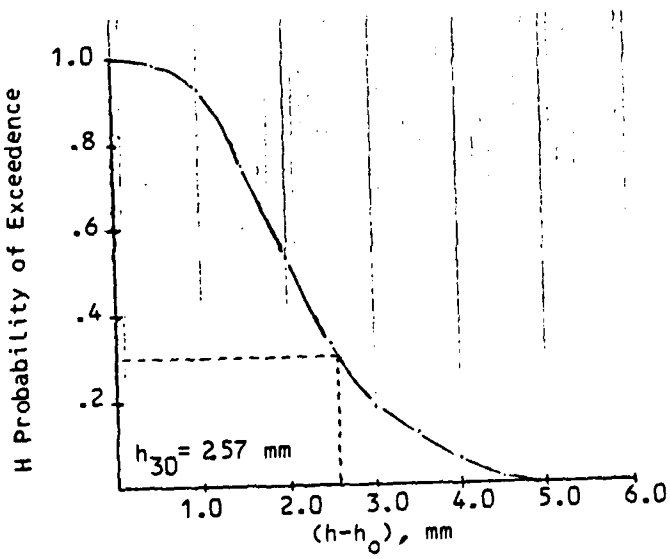

1.0
.8
.6
.4
.2
H Probability of Exceedence
h30=3.25 mm
-1.0 0 1.0 2.0 3.0 4.0 5.0 6.0 7.0
(h - h0), mm

APPENDIX A (CON'D)

C. PHOTOMICROGRAPHY DATA G-3 SAMPLE


1.0
.8
.6
.4
.2
Y Probability of Exceedence
h_o=1.90 mm
1.0
2.0
3.0
4.0
5.0
6.0
$(y-y_o)$, mm


n=133
0.00
1.00
2.00
3.00
4.00
5.00
6.00


1.0
.8
.6
.4
.2
H Probability of Exceedence
h_{30}= 2.57 mm
1.0
2.0
3.0
4.0
5.0
6.0
$(h-h_o)$, mm

DISTRIBUTION

	Copies
Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	12

NDW-NSWC(W)-5605/1 (Rev. 5-78)

TO AID IN UPDATING THE DISTRIBUTION LIST
FOR NAVAL SURFACE WEAPONS CENTER, WHITE
OAK TECHNICAL REPORTS PLEASE COMPLETE THE
FORM BELOW:

TO ALL HOLDERS OF NSWC MP 81-259
By M. D. Jobe, Code K24
DO NOT RETURN THIS FORM IF ALL INFORMATION IS CURRENT

A. FACILITY NAME AND ADDRESS *(OLD) (Show Zip Code)*

NEW ADDRESS *(Show Zip Code)*

B. ATTENTION LINE ADDRESSES:

C.

☐ REMOVE THIS FACILITY FROM THE DISTRIBUTION LIST FOR TECHNICAL REPORTS ON THIS SUBJECT.

D.
NUMBER OF COPIES DESIRED ________________

DEPARTMENT OF THE NAVY
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MD. 20910

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
DEPARTMENT OF THE NAVY
DOD 316

U.S. MAIL

COMMANDER
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MARYLAND 20910

ATTENTION: CODE K24, M. D. Jobe

DATE
FILMED